# THE EXPLOSIVES ENGINEER

FORE-RUNNER OF PROGRESS IN MINING-QUARRYING & CONSTRUCTION

JANUARY · FEBRUARY · 1961

VOLUME 39 · NUMBER 1

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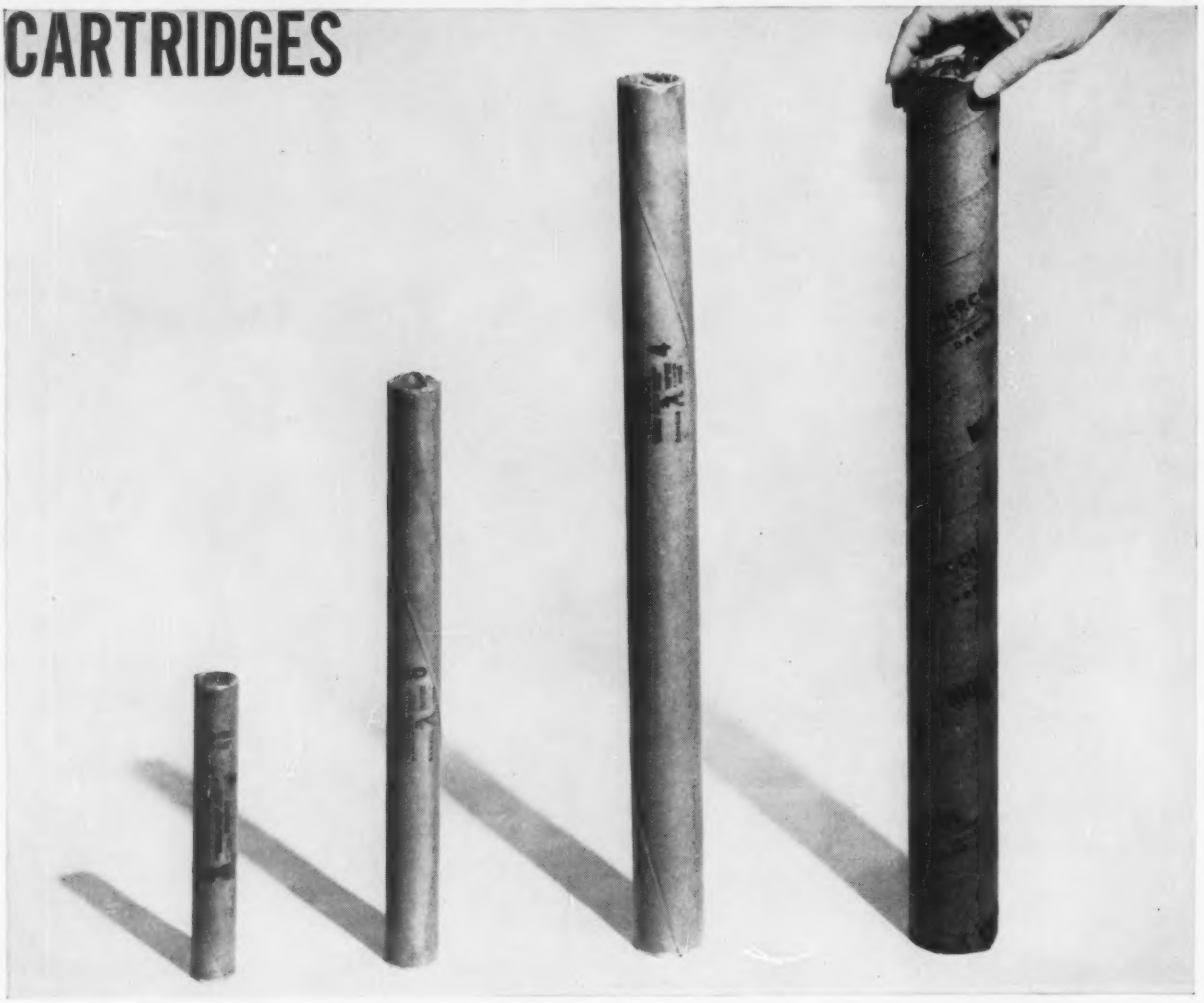

The Hercol series of low-cost, cap-sensitive, high-ammonia-content explosives are now available in cartridges of small diameters and standard lengths, as well as in the larger diameters and special packings.

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|---|---|---|---|---|
| Fumes | Good | Good | Good | Good |
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| Cartridge diameter, in. | 4 to 8½ | 1 to 3½ | 1 to 3½ | 1 to 3½ |
| Weight strength, % | 70 | 68 | 68 | 68 |
| Cartridge strength, % | 48 | 50 | 34 | 19 |
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# THE EXPLOSIVES ENGINEER

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Forerunner of Progress in Mining, Quarrying, Construction


Thanks to TV, it is difficult for the average person not connected with the industry to realize that mining is not just a grizzled old prospector, with a burro loaded with supplies and tools who luckily finds ore and just digs it out with a pick and shovel. Mining has come far since those days.

Today many companies maintain extensive research facilities, not only to discover more or better ways of using their products, but also better and more economical methods of obtaining the basic materials.

One such project is the study of "burn-cut drift rounds" recently conducted at the St. Joseph Lead Company at Bonne Terre, Missouri, under the direction of Richard L. Bullock, head mine research engineer. We are fortunate in being able to present to our readers the results of Mr. Bullock's researches in a two-part article, "Fundamental Research on Burn-Cut Drift Rounds." Part I of this article, which discusses the fundamental concepts and related information on burn-cut patterns, starts on page 7.

° ° °

If Leonidas Merritt and his brothers could reappear on the Mesabi, we are sure they would stare in amazement at the many changes that have taken place since their discovery of iron ore in 1887.

Nearly three-quarters of a century has elapsed since their discovery. In this time the Mesabi area, in supplying much of the ore for the normal iron needs of the nation plus the unusual demands created by two world wars, has undergone constant and progressive expansion. An outstanding example of the progressive expansion and growth of the area is the Pierce Mine of the Hanna Ore Mining Company. L. H. Houck, in his article starting on page 20, traces the history and development of the Mesabi and describes the geology and techniques used at the Pierce Mine.

° ° °

Once again it is our privilege to join with the entire heavy-construction industry in honoring two men for outstanding achievement in this field. On January 25, 1961, with proper ceremony, The Moles presented their coveted award to Herman Brown, president of Brown & Root, Inc., of Houston, Texas, and to Harry T. Immerman, vice president and chief engineer of Spencer, White & Prentis, Inc., of New York City.

More details of this award may be found on page 27.

° ° °

An interesting and successful method of drilling and blasting has been used in excavating a new outlet from the harbor of Norrköping on the Swedish east coast. Named the "Lindö" method after the canal it helped build, the system features drilling through the overburden and then into the rock. This is accomplished by use of rock steel surrounded by a steel tube equipped with a circular crown bit. When the bit is withdrawn, the tube constitutes the connection between the surface and the rock.

For a description of this method, we suggest you turn to page 28 where J. Grindrod, a British journalist, describes this work on the Lindö canal.

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EDITORIAL STAFF: JAMES J. O'NEILL, *Editor;* THOMAS E. MILLER, *Associate Editor;* GERTRUDE A. DONNELLY, *Associate Editor;* EDWARD L. GRANT, *Art Editor;* HOWARD B. DICKSON, *Production Manager;* A. J. ACKERMAN, *Advertising Manager;* MONTGOMERY R. BUDD, *Director.*

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BPA

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| TUNNEL | LOCATION | LENGTH IN FT. | BORE |
|---|---|---|---|
| Bingham Tunnel #5490 | Utah | 17,951 | 20′ x 25′ |
| Flaming Gorge Tunnels | Utah | 1,100 | 20′ x 25′ |
| Salt Lake By-pass | Utah | 8,000 | 8′ x 8′ |
| Columbia Tunnel | Utah | 8,500 | 7′ x 14′ |
| 79th St. Chicago Tunnel | Illinois | 24,400 | 19′ |
| Washington, D.C. Tunnel | District of Columbia | 6,800 | 17′ |
| Eucumbene-Tumut | Australia | 36,916 | 24′ |
| Diversion Tunnel | Australia | 3,538 | 18′ x 20′ |
| Murrumbidgee-Eucumbene | Australia | 53,800 | 11.3′ |
| Cumbaya Hydro-Electric Project | Ecuador | 27,800 | 12′ |
| Tooma-Tumut | Australia | 49,520 | 12.5′ |
| Hanabanilla Tunnel | Cuba | 22,000 | 14.1′ |
| Glen Canyon—Diversion | Arizona | 2,900 | 46′ |
| Access | Arizona | 12,000 | 23′ |
| Spillway | Arizona | 2,200 | 50′ |
| Cable Control | Arizona | 1,300 | 7′ |
| Fremont Canyon | Wyoming | 22,000 | 19′ |
| Vasquez Tunnel | Colorado | 16,000 | 7′ |
| Quandary Tunnel | Colorado | 6,000 | 6′ x 8′ |
| McCullough Tunnel | Colorado | 6,500 | 6′ x 8′ |
| Rampart Range Tunnel | Colorado | 4,200 | 8′ x 9′ |
| Silver Falls Hydro-Electric Project | Ontario | 10,400 | 17′ |
| SAGE Tunnels | Ontario | 7,000 | 10′ x 10′ |
| Quebec Cartier Railway | Quebec | 5,000 | 18′ x 22′ |
| Montreal Sewer Tunnels | Quebec | 15,000 | 9′ |
| Bridge River Hydro-Electric Project | British Columbia | 13,000 | 18′ |
| Cooper Lake Hydro-Electric Project | Alaska | 4,600 | 12′ |
| Blue Lake Hydro-Electric Project | Alaska | 9,000 | 12′ |
| Vancouver PO Project | British Columbia | 2,200 | 8′ |
| Navajo Dam | New Mexico | 3,200 | 18′6″ |

# On these 81 tunnels... the rock

| | | | |
|---|---|---|---|
| B&O Railway | West Virginia | 581 | 25′ |
| Foothills Parkway Vehicular | North Carolina | 840 | 32′ |
| Smith Dam Diversion | Alabama | 1,946 | 26′ |
| Flannagan Diversion | West Virginia | 780 | 21′ |
| Blue Ridge Vehicular | North Carolina | 900 | 32′ |
| Canyon-Ferry Tunnel | Montana | 12,000 | 7′ |
| Luray Vehicular | Virginia | 1,000 | 32′ |
| Kettle Creek Diversion | Pennsylvania | 900 | 19′ |
| Allegheny Sewer Authority | Pennsylvania | 5,500<br>52,000 | 8′<br>8′ to 14′ |

**Total length of tunnels: 1,112,735 FEET**

**Period covered: Tunnels completed or in progress during the past five years ONLY.**

| TUNNEL | LOCATION | LENGTH IN FT. | BORE |
|---|---|---|---|
| Neonsack Tunnel | Washington | 8,800 | 7′ x 8′ |
| Avamate Water Tunnel | Ohio | 3,000 | 14′ |
| West Delaware Aqueduct | New York | 227,040 | 14′ |
| Newtown Creek Tunnel | New York | 8,045 | 11′6″ |
| Worcester Diversion Tunnel | Massachusetts | 4,800 | 19′ |
| Western Pacific Tunnels #4 & 5 | California | 12,800 | 22′ x 28′ |
| Clear Creek Tunnel | California | 57,030 | 17′6″ |
| Lafayette Tunnel | California | 15,840 | 9′6″ |
| Cherry Valley Power Tunnel | California | 29,400 | 12′6″ |
| Eleanor-Cherry Tunnel | California | 6,400 | 11′ |
| Mammoth Pool Tunnel | California | 42,240 | 21′ |
| Haas Tunnel | California | 32,800 | 13′ |
| Jaybird Tunnel | California | 23,300 | 15′ |
| Camino Tunnel | California | 27,220 | 13½′ |
| Western Pacific Railway #2 & 3 | California | 5,600 | 22′ x 28′ |
| Mammoth Pool Diversion Tunnel | California | 1,300 | 28′ |
| Wishon Diversion Tunnel | California | 1,400 | 15′ |
| Poe Tunnel | California | 36,960 | 19′ x 27′ |
| Trinity Dam Diversion Tunnel | California | 2,800 | 34′ |
| Western Pacific Railway Tunnel | California | 3,000 | 22′ x 28′ |
| Caribou Power Tunnel | California | 9,240 | 12′ |
| Butt Valley Power Tunnel | California | 10,560 | 13′ |
| Dez Dam—Diversion Tunnel | Iran | 2,160 | 50′ |
| Access Tunnel | Iran | 10,820 | 21′ x 18′ |
| Glendale Tunnel | California | 18,000 | 17′ |
| Green Springs Tunnel | Washington | 2,100 | 6′ |
| Cascade Tunnel | Washington | 4,800 | 6′ |
| Pacific Power & Light—Diversion Tunnel | Washington | 3,000 | 32′ |
| Power Tunnel | Washington | 1,575 | 25′ |
| Penstock Tunnels | Washington | 1,950 | 13′ |

# rills are all Gardner-Denver

| | | | |
|---|---|---|---|
| Faroday Tunnel | Washington | 2,463 | 23′ |
| Pelton Dam Tunnel | Washington | 600 | 20′ |
| Coregan Dam—Diversion | Washington | 1,800 | 18′ |
| Outlet & Penstock | Washington | 2,070 | 15′ |
| Hills Creek Dam Tunnels | Washington | 1,600 | 18′ x 10′ |
| Main Relief Sewer Philadelphia | Pennsylvania | 4,200 | 16′ |
| Bull Run Dam | Oregon | 1,200<br>1,000 | 9′<br>18′ |
| Chicago Water Tunnel | Illinois | 2,250<br>1,400 | 16′ stub<br>20′ stub |
| Costile Falls Tunnel | Washington | 900 | 12′ |


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## Marcus David Banghart

VICE PRESIDENT

NEWMONT MINING CORPORATION

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### A Biography

With Africa torn by strife and internal dissension, riots and bloodshed directed toward the colonialist powers, and everywhere empires tottering on the brink of revolution, one man still has faith in the people of that dark continent and the likelihood that they will come to a stabilized and peaceful future. He is Marcus D. Banghart, vice president of Newmont Mining Corporation. Marcus Banghart, or "Bang" as he is generally known, believes firmly that the people of South Africa—the Bantus, the colored, and the white—are solving the problem of living and working together in harmony, and that the chances are excellent that the strife seen by other African lands will not come to the Union of South Africa. He bases this opinion upon seventeen years' observation gained while living and working in South Africa.

Bang was born in the little town of Johnstown, Nebraska, educated in the Lincoln public schools, and graduated from the University of Nebraska with a B.Sc. degree in geology. He began work as a miner with Anaconda Copper Company as a shift boss in Butte in 1923. Four years later he had his first taste of work in foreign lands when he became mine superintendent for the South American Development Company at Portovelo, Equador; in 1930 he became mine superintendent and manager of the Lucky Tiger Combination Gold Mining Company properties in Mexico, Nevada, and California.

In 1943, he joined the Newmont organization and worked with its subsidiaries in British Columbia and Ontario, Canada, until 1940, when he was made general manager of the O'Okiep Copper Company at Nababeep, South Africa. He was made general manager also of the Tsumeb Corporation, Ltd., another Newmont-managed property, in 1947; and in 1953 became managing director of both O'Okiep and Tsumeb. A year later he became a vice president of Newmont, and returned to this country to make his headquarters at the Newmont offices in New York City.

Besides these positions, Bang is president of the Idarado Mining Company, Ouray, Colorado; vice president of Dawn Mining Company, Ford, Washington; vice president of Resurrection Mining Company, Leadville, Colorado; and director of Newmont, Idarado, Dawn, and Resurrection, and of Granduc Mines, Vancouver; Hecla Mining Company, Wallace, Idaho; O'Okiep; Palabora Mining Company, Johannesburg; Sherrit Gordon Mines, Toronto; Southern Peru Copper Corporation, New York; Tsumeb; and Winkelhaak Mines, Ltd., Johannesburg.

The 1961 recipient of the William Lawrence Saunders medal for distinguished achievement in mining other than coal can take pride in the citation accompanying this most cherished award of the mining profession: "For the development of new mining techniques and overcoming many operating difficulties, resulting in O'Okiep and Tsumeb becoming low-cost producers under his capable management."

In the past decade, which includes Bang's stewardship of O'Okiep, its production of copper ore has grown from 960,000 short tons to 1,775,000 per year, and its smelter production from 23,000 short tons to 39,000.

Bang is so convinced of the future of South Africa that he strongly endorses his company's decision to embark upon a $30,000,000-expansion program for O'Okiep and Tsumeb. He feels that Americans have misinterpreted the Apartheid policy of South Africa, which is in no sense comparable to the racial conditions in this country. He points out that the government has set aside great tracts of land, termed reserves, some of which are rich farm lands, where no whites can come in and develop an enterprise. The employes of O'Okiep and Tsumeb are paid such wages and benefits that thousands of natives from other African countries seek admittance to South Africa to work in the mines. To top it off, Bang says he fully intends to return to Cape Town to live after his retirement.

Bang lives with Mrs. Banghart on Rock Ridge Avenue, Greenwich, Connecticut. Their five children are either on their own or in school. His daughter, Lurena Gayle, a graduate of Johns Hopkins, works in a Cape Town Hospital; his eldest son, David, a graduate of Lehigh, is a first lieutenant with the American forces in Germany; Richard, a graduate of the Montana School of Mines, is a mining engineer with Tsumeb; John is doing his military service with the Marines; and Peter is a student at the University of Nebraska.

MARCUS DAVID BANGHART

# Editorial

## It's Your Nickel

The succinct title of a local radio program, "It's Your Nickel," a reminder of the time when you could buy a phone call for a nickel, has always intrigued us with its refreshing realism. You call the announcer, using your dime, and he will air your current complaint about government, taxes, or the chuckholes in the streets after a hard winter. We might pin the same tag on the U. S. foreign aid program funds, which are currently under scrutiny in Washington because, having given away so much money, our largess is beginning to threaten our gold reserves. Now we would like to persuade the Western European powers to help us support the underprivileged peoples of the world in our efforts to buy their friendship. Unfortunately, the chancelleries of the Old World seem to be distinctly cool to our suggestion that they begin picking up the check for a Free World foreign aid program. Their rejoinder seems to be, "Well, you can do what you like with your nickel, but what friends have you been able to buy with the dollars you have poured across the world?"

It's a good question. Foreign aid, admirable in its altruistic conception of a helping hand to the depressed peoples of the world, makes us wonder whether the good will of the small nations thus bought can survive the cessation, or even a partial cut, in the flow of dollars; whether the amity of our friends will flourish after polite requests for repayment of the loans. Bankers tell a hoary old joke about an old banker sitting on his front porch, listening to a friend's report that one of the leading citizens of the village had just been berating the banker as a tight old skinflint. To which the pillar of the local bank replied, "That's funny, I never lent him any money." And social workers tell a story about a pitiful old man found destitute in his cold, dreary room who could be persuaded only with difficulty to swallow his pride and accept a government relief check. But after six monthly checks came in, the once proud old gentleman came to the relief office on the day his seventh check was due and pounding on the desk, demanded, "Where is my check?"

Perhaps we should ask ourselves: How staunch is the good will we have bought with the gold flowing out of our coffers in recent years?

## Red Metal

A new mining nation may be about to appear on the horizon, if reports of new mineral deposits of great magnitude can be given credence. The existence of huge bodies of ore in China, reported to a symposium on that nation's scientific development by the American Association for the Advancement of Science, makes it appear that Red China, always that mysterious, inscrutable, mystical Far East, may some day in the dim, distant future, be a great industrial power and metal producer.

China, it seems, according to the papers presented before the association's annual meeting, has developed a tremendous scientific geological prospecting program which has uncovered very significant ore bodies. A reserve of 7 billion tons of iron ore in the Shansi area, and another deposit of 3 billion tons in Honan province; a molybdenum deposit reputed to be richer even than that of Climax, Colorado; a large deposit of ilmenite on the island of Hainan; and an unverified nickel deposit—all this plus plentiful supplies of coal, including coking coal, which, however, is not located where it is needed, would seem to constitute a wealth of ores for the ancient empire.

The techniques and equipment necessary to get these ores out, however, are something else again. China here runs all the way from modern technology to the most primitive methods depending almost entirely on manpower, not only to dig the ore, but to transport it. As any mining man knows, ore in the ground is one thing, and a highly developed industrial society which can make use of this ore is another. When China will reach that stage is a question that our sons or our grandsons may not see answered.

# Fundamental Research On Burn-Cut Drift Rounds

**Part I of this article discusses the fundamental concepts and related information on burn-cut patterns. Part II will cover the experimental process that developed an operating burn-cut drift round as well as the performance records now being achieved**

RICHARD L. BULLOCK*

PART I

THE burn-cut method of driving a drift or tunnel has been successfully practiced for many years in all parts of the world. The fact that generally a deeper round may be broken, as compared to other methods of drifting, is a compelling economic factor to the mine operator or tunnel contractor. In recent years, the trend to jumbo-mounted drills, more accurate timing of electric delay caps, and loading units with higher capacities have helped the burn-cut drift pattern to develop.

Nearly five years ago the Mine Research Department of the St. Joseph Lead Company at Bonne Terre, Missouri, was assigned the task of developing a method whereby long drift rounds (10 to 12 ft.) could be successfully broken. The drift round being used universally in the Lead Belt at the time was a standard pyramid cut capable of breaking 5 to 7 ft. in our rock, in a 10 by 12-ft. drift. This round is still being used in the older mines where the existing equipment does not adapt itself to the burn-cut method of drifting. Nevertheless, it represents a well-balanced cycle of clean, drill, and break on each shift. However, the new lead mines of St. Joe's are being equipped with modern drill jumbos and are now employing the burn-cut method.

The information contained in this article covers a summary of the existing information related to the problem taken from the literature, the experimental development of a successful burn-cut pattern, and a discussion of how the burn-cut rounds are currently being used in the new mines.

### The Burn-Cut Method

Any cut pattern that depends upon one or more open holes drilled parallel to the loaded holes to furnish stress relief when the loaded holes are fired is known as a burn cut. These patterns are also known as shatter, burn out, Michigan, and Cornish cuts. It is likely that the name "shatter cut" more closely describes the breaking action which takes place within the cut. The last two names imply the cut's derivation.

The principal advantages of the burn-cut design can be summarized as:[1]

1. The burn cut allows a deep pull, even in tough rock.
2. The burn cut is simple to drill because all holes are parallel.
3. The fly rock from the cut is reduced to a minimum as there is a comparatively small component of forces away from the tunnel face.

*Head Mine Research Engineer
St. Joseph Lead Company
Bonne Terre, Missouri

Likewise, the disadvantages have been stated as:

> The drill holes (one or more) at the center must, usually, be of larger diameter than the other holes in the round. This type of cut entails the largest drilling footage per cubic foot and a heavier consumption of explosive than the other types.[2]

Other disadvantages discussed later are: the deviation of the holes away from parallel alignment may cause the cut to fail, and sympathetic detonation between closely spaced holes may cause holes to fire out of order, thus causing the cut to fail.

### Design of the Experimental Burn Cut

From our investigation we found there are many factors which must be taken into consideration in designing a burn cut. These factors are discussed separately.

#### *Type and Structure of Rock*

The type of rock in which the burn cut is being drilled is probably the most influential factor affecting the success of the cut. In an excellent paper on burn cuts, E. Steidle[3] lists 39 different types of rocks in seven classes, ranging from plastic to brittle. (See Table I.) In general, the plastic rocks are more difficult to break in a burn cut than are the brittle rocks.

The structure of the rocks is also an important factor in designing the burn cut. Bedding planes, faults, soft seams, or any other such discontinuity in the rock offers a special problem to the design of the burn cut. Generally, such structures allow the force of the explosive to dissipate rather than do the work that it was designed to do.

The rock in which the burn cuts were tested was the Bonneterre dolomitic limestone formation. The Bonneterre formation (upper Cambrian age)

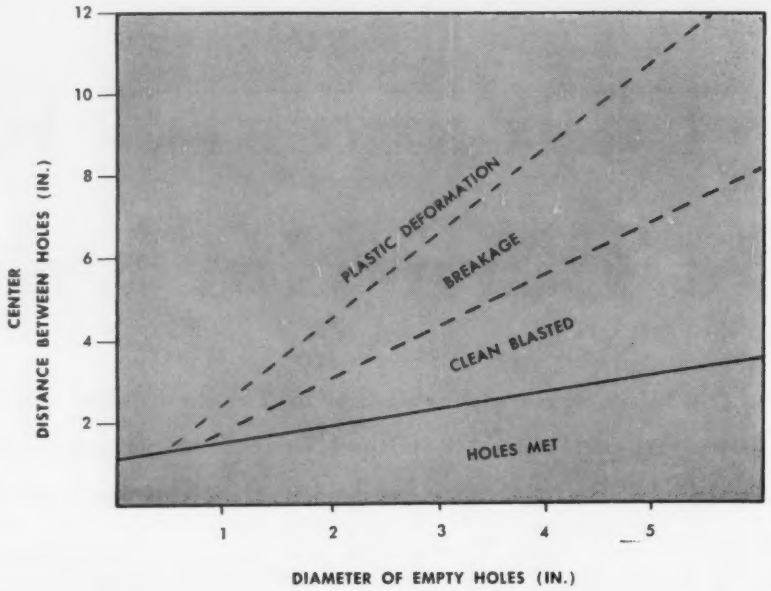



**FIGURE 1: This graph shows how the results vary when a cut hole is placed at various distances from different size relief holes. The ideal burn-cut pattern spacing should fall within the "clean blasted" zone. (After Langefors.)**

**TABLE I**

**Classes of Rock Types Ranging from Plastic to Brittle**

| A | B | C | D |
|---|---|---|---|
| Gypsum | Limestone—soft | Limestone—medium | Sandstone—soft |
| Shale—very soft | Shale—soft | Sandstone—soft | Limestone—hard |
| Clay | Carboniferous limestone | Shale—medium | Shale—hard |
| Very decomposed rock | Calcite | Sand shale | Bituminous shale |
| | Medium decomposed rock | Semisiliceous limestone | Crystalline limestone |
| | | | Siliceous limestone |

| E | F | G |
|---|---|---|
| Granite—soft | Quartz | Granite—hard |
| Hematite | Quartzite | Quartzite—fine grained |
| Sandstone—hard | Conglomerate quartz | Silex |
| Mica schist | Marble | Tactite |
| Clay conglomerate | Granite—medium | Silicon-bearing rocks |
| Silicate | Sandstone—hard | |
| Silicon-bearing rocks | Silicon-bearing rocks | |

is nearly 400 ft. thick. In places, it is covered by the Davis shale and rests on the Lamotte sandstone.

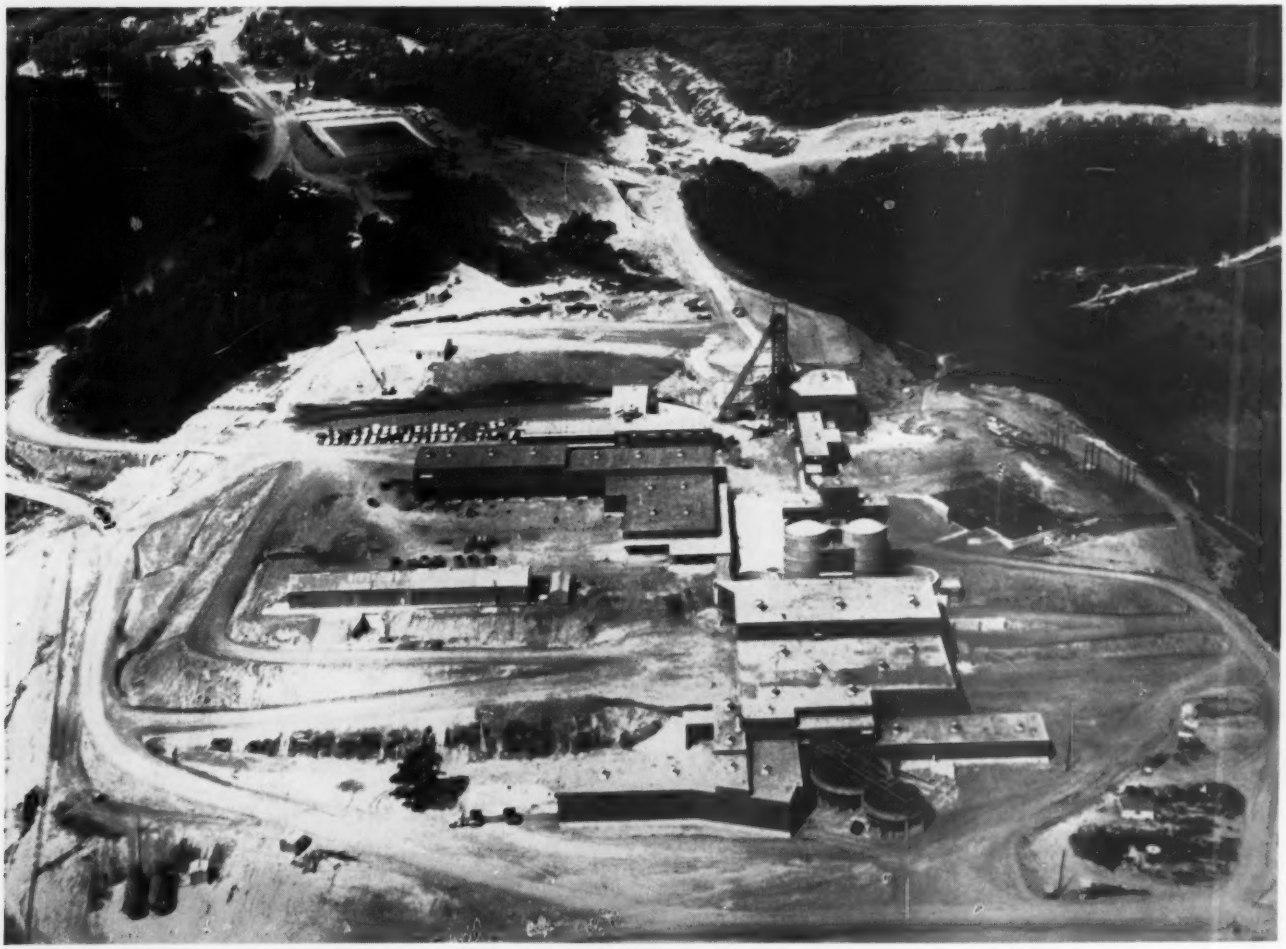
Locally, the "Bonneterre" has been divided into zones. While all of the zones of the Bonneterre are basically dolomitic limestone, each zone has somewhat different characteristics. Even rock within the same zone may vary considerably in different mines over the district. It is the inconsistent nature of the rock that offers the most difficulty in the development of a successful burn-cut pattern. As well as varying rock types, the Bonneterre formation contains many minor slips, joints, and vertical channels. Generally, such discontinuities will cause a burn cut to break short of the desired depth. Of the rocks listed in Table I, the Bonneterre would probably fall between Classes C and D.

***Position and Size of the Holes***

There are many different types of burn-cut patterns. Each type differs mainly in the amount of stress relief that is given to the loaded holes when they are detonated. Stress relief can be defined as the ease with which the rock between the open holes and the loaded holes fails and expands freely into the open holes. The larger the open holes, the more that there are, and the closer they are spaced, obviously the greater the stress relief that is given to the breaking rock. Likewise, the more stress relief that is given, the deeper the burn cut will break. Evidence of this is found in other research work by Yancik[4] on large-hole burn cuts.

There is, of course, a practical limit to the size of the open holes, which is determined primarily by the length of time and type of equipment necessary to drill them. It is believed that the diameter of the cut holes containing the explosive has little influence on the blasting of the burn cut. In a paper by Noren[5] on the effectiveness of cartridge diameter of dynamites, he found little difference in breaking a burn-cut drift round when the small-hole diameter, as well as the explosive diameter, was varied.

One of the important factors to consider in planning the spacing of the holes is the type of failure that occurs between the loaded holes and the open holes. The chart in Figure 1 illustrates this point. On this chart, Langefors[6] shows that there are four conditions which might occur, depending upon the hole spacing. The ideal burn-cut pattern spacing should fall within the zone "clean blasted." This allows the



**VIBURNUM MILL: An excellent aerial view of St. Joseph Lead Company's new Viburnum mill and surface facilities. This modern plant started operating in July of 1960.**

rock not only to break, but also be thrown out of the cut. In the zone of "breakage," the rock will be broken, but much of the rock will hang in the cut. In brittle rock, the cut will probably still break, but in plastic rocks, the cut may fail because of recompaction of the rock. When "plastic deformation" occurs, the rock between the holes will flow by shear action into the open holes, but there will be little increase in the cut opening. The rock will be recompacted in the open holes. This type of occurrence is known as "freezing" or "fixation" of the burn-cut holes. One point which Langefors failed to illustrate on his chart is the fact that the rock type may also influence the type of breakage. Extremely plastic rock types tend to "flow" and not break, even in the breakage zone. The explosive can also influence this phenomenon, but this will be discussed later.

As to the actual spacing needed to obtain clean blasted rock, experimentation in the particular rock type is necessary. Steidle[3] presents a graph (Figure 2) which will act as a guide to the necessary experimentation. The rock classes refer to Table I.

The test work in the rock of the Bonneterre formation compared favorably with Langefors' hole-spacing chart. For a 1⅞-in.-diameter open hole, the upper limit of the breakage zone was between 4 and 5 in. At this relief hole size, it was impossible to find the upper limit of the clean blasted zone since the holes would be so close together that with normal drilling deviation they would meet. When 3-in.-diameter relief holes were used, the upper limit of the clean blasted line was about 5 in., while that of the breakage zone was thought to be about 6½ in. Limits varied with the explosive used.

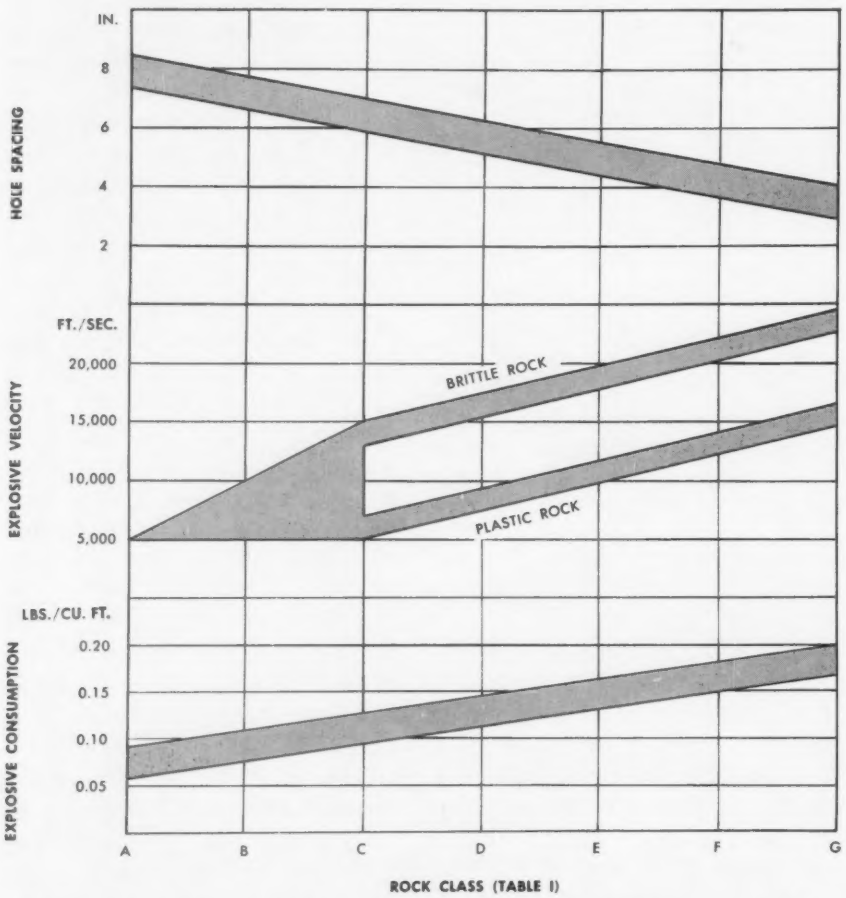



**FIGURE 2: The hole spacing and the amount of explosives needed to obtain proper breakage in a burn-cut is shown in this graph which may be used as a guide for experimentation. The rock classes refer to those shown in Table I. (After Steidle.)**

### *Amount and Type of Explosive*

There is a definite tendency in designing or experimenting with a burn cut to overcharge the cut. Overcharging may cause the broken rock to be compacted into the open holes which, in turn, will obstruct the burn opening, and cause failure.

Langefors[6] gives an empirical formula that may be used to calculate the amount of explosive necessary to break a burn cut. It is based on the diameter of the empty holes (d) and the distance between the holes (a) in inches. The amount of explosive necessary (e) is in lb./ft. The formula is:

$$e = 2.72 \times 10^{-2} (a/d)^{3/2} (a - d/2).$$

The formula was first determined on a scale model and later adjusted to full-scale blasting. It does not take into account the various rock types, nor the strength or velocity of explosive necessary to break the cut. It is, therefore, inadequate to apply to all conditions that are encountered.

Steidle[3] takes a somewhat different approach to the problem of the amount of explosive necessary to break the cut. Based on the rock types listed in Table I and using the graphs in Figure 2, the velocity of the explosive and the amount of the explosive necessary are found. The amount of explosive is based on the volume of the burn-cut opening produced by blasting the cut. Steidle's method does not take into account the variation in the open hole diameter. It would, from his graphs, appear that it would take the same amount of explosive to break to a large 4-in. hole as it does to a 2-in. hole. This supposition seems doubtful since the 4-in. hole would offer considerably more stress relief.

Both Langefors' and Steidle's methods of calculating the amount of explosive necessary to break a burn cut have limitations and shortcomings; yet they are the best guides that can be found in the literature. The main reason that a more exact method than those presented is not available is that, first, the exact action that breaks the rock between the burn-cut holes is not definitely known, and, second, the knowledge of the explosive parameters

that will accurately measure the action of an explosive within a bore-hole is limited. There are two basic variables to be considered: the type of explosive, and the type of rock. The problem is to find an explosive that will produce the right action against the rock between the burn-cut holes to cause the rock to fail without recompacting. The mechanics of the rock failure in the shatter cut will be discussed in detail in a later section. To get the proper breaking action to take place between the explosive and the rock of the Bonneterre was a most difficult task. Even when the holes were supposedly well within the clean breaking zone, the cut would become obstructed with broken rock. Several explosives of varying strength and detonating velocities were tried; but, for the most part, the results were poor. It finally became obvious that only a limited amount of explosive energy is needed to shatter the rib of rock between the loaded and the open holes and expel it from the cut. If there is a great excess of energy present, it will be used to recompact the broken material. Many unsuccessful attempts were made to decrease the energy per foot of hole by not tamping the explosive and by deck-loading the explosive column. Finally, it was found that it would take an explosive with a very low detonation velocity as well as a low strength to provide just the right amount of energy. The explosive selected was a permissible which detonates at 5,500 f.p.s. Later it was found that Hercomite® 7A does nearly as well.

One interesting point was proved conclusively for burn cuts fired in the rock of the Bonneterre. Each loaded hole of the burn cut must be charged, but not tamped, its complete length, i.e., all the way out to the collar. If this is not done, the cut will break only where the explosive is placed. It then leaves a solid wall of rock on the face.

### *The Occurrence of Sympathetic Detonation*

Closely related to the type of explosive needed is the possibility of sympathetic detonation between closely spaced holes of the burn cut. This phenomenon is sometimes known as "flash-over." Because the holes of a burn cut are usually spaced close together and drilled parallel, the firing of one hole may set off the other holes. This will upset the sequence of the firing order of the burn cut and may cause the cut to fail. There are, of course, places where burn-cut patterns are being used that fire all of the holes instantaneously. Obviously, flash-over would not have a chance to occur if all holes were fired together.

Sympathetic detonation occurred numerous times over a distance of 10 in. in dolomitic limestone of the Bonneterre formation using a 40% semigelatin explosive. On this same subject, Langefors[6] states:

> A secondary condition which must be considered is that flash-over in this case must be prevented both between opposite holes and between contiguous ones. It implies that the drill holes where they are fully charged, must not be allowed to be closer than 20 cm (7.78 in.).

Structural conditions in the rock, such as open channels, clay seams, and slips, can cause sympathetic detonation to occur. Any moisture-bearing stratum that cuts both loaded holes may propagate a sufficient shock to cause sympathetic detonation. The loaded holes being too close together, because of drilling deviation or improper alignment, may be another factor influencing flash-over. The subject of drilling deviation will be discussed later. Still another cause of sympathetic detonation may be the overcharging of the holes.

### *Types of Delay Primer and Firing Order*

The proper sequence of firing for each particular burn-cut pattern will have to be worked out for the rock type in which it is being used. The main danger is allowing too many holes to go off at one time, which may plug the burn opening.

There are five methods of obtaining a delay in the firing order of holes:

1. Standard delay electric caps (with intervals of 0.75 to 2.5 sec.).
2. Intermediate or rapid delay electric caps (with intervals of 100 to 1,200 milliseconds).
3. Millisecond delay electric caps (with intervals of 8 to 250 milliseconds).
4. Delay of safety fuse.
5. Detonating cord with delay mechanisms.

The standard delay electric caps offer the best chance to perform experimental work on burn cuts. By using a cap with a long delay interval, one is sure that there is ample time for the rock from each hole to break and be expelled from the cut, before the next hole goes off. Also, by listening to the firing order one can determine when sympathetic detonation occurs. However, standard delay caps are being replaced in many mines by a new series of intermediate delay electric caps. The intermediate caps have a much shorter interval between delays than do regular caps, are more accurately timed, and are offered in 15 delay intervals. These caps also allow enough time for each hole to break and expel the rock before the next hole goes off, but one can hardly determine by ear when sympathetic detonation occurs. If a successful burn-cut pattern has already been designed, then the new intermediate series offer a great flexibility in the burn-cut round.

The so-called millisecond or short-period delay electric caps have a large number of delays available, but it is believed that the time interval between the first few delays is not sufficient to allow proper breaking action to take place. While these caps are fairly accurately timed, the chance of their overlapping one another is present. Evidence of this was reported by Yancik.[4] Therefore, if millisecond delays are to be used, it would be more assuring to skip every other delay for the first few delays.

Since burn-cut holes are spaced so close together, the use of safety fuse is not recommended. The first hole detonating might cause the fuse to be cut off or pinched, thus causing a misfire. Likewise, detonating cord is also vulnerable to cutoffs and is not recommended for this type of use.

### *The Amount of Drill Hole Deviation Permissible*

One factor that is often overlooked in designing a burn cut is the amount of hole deviation that can be expected and how it will affect the results of the cut. Since the success of burn-cut patterns depends on holes in close proximity to each other to be drilled parallel, the hole deviation is an important factor.

There are two main reasons why drill hole deviation occurs: (1) the hole is collared in the wrong place or in the wrong direction; (2) seams or crevices in the rock cause the drill to deviate from the intended course. The problem of hole deviation, sometimes known as "drill scatter," is discussed at length by Langefors.[6,7]

He first assumes that drill scatter will follow a normal statistical distribution. With this assumption, he presents a graph correlating the hole deviation with the depth of the holes. The graph that he gave as an illustration is shown in Figure 3. It is proposed that drilling scatter be given as the deviation of five-sixths (84%) of the holes drilled and expressed as a percent, i.e., if five-sixths of the holes have deviation of less than one cm. per m., then the deviation is 1%. Figure 3 represents the drill scatter for hand-held drills in homogeneous rock. The deviation for line "A" is for drilling with points of direction. Line "B" is the deviation without points of direction. Line "C" is the deviation found in normal drilling of horizontal holes. Line "A" would then represent 1% deviation; line "B," 2% deviation; line "C," 4% deviation. For drilling from stationary column or jumbo, the deviation should be less than 0.5%.

How the deviation affects the design of the burn cut was also covered by Langefors. The important questions of the most suitable distances between the holes, and their geometric arrangement, have been put on a basis that makes it possible to deal with the problem by calculation. An analysis can thus be made of different methods of attack that can be employed against a tunnel face. Such an analysis should include data of drilling deviation from errors in alignment and deviation because of the unevenness of the rock. The drill scatter permissible for each hole in a burn-cut pattern is first established. Then how many and which of the holes must be placed within the limits indicated, so as to fall within the zone of clean breaking and how, from a statistical aspect, conditions vary at different depths of the hole can be determined. The drill hole deviations in this case will set a definite limit for the possible advance.

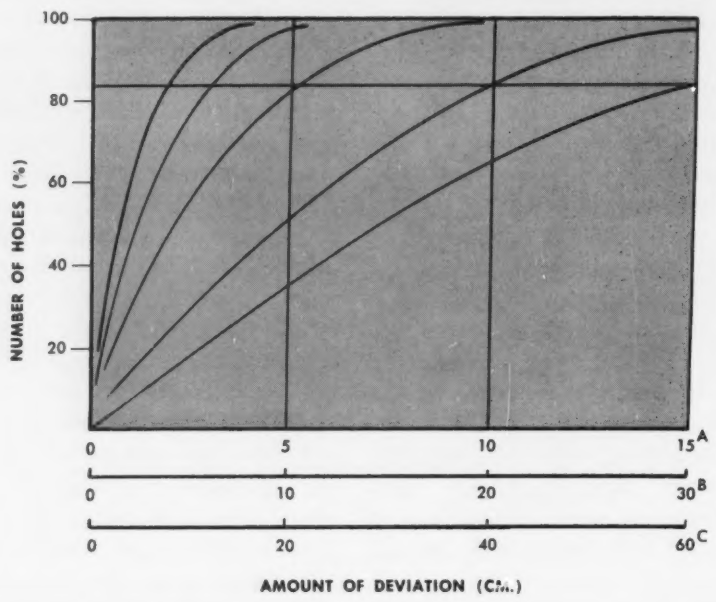



**FIGURE 3: Hole deviation for hand-held drills in homogeneous rock. The deviation for line "A" is for drilling with points of direction. Line "B" is the deviation without points of direction while line "C" is the deviation found in normal drilling of horizontal holes. (After Langefors.)**

### *The Use of a Booster Charge*

Any explosive charge that is in the bottom of the empty burn-cut holes, and fired after the cut holes in order to expel the rock out of the cut, is known as a booster charge or "kicker." Steidle[3] mentions the possible use of a booster charge in his paper on burn cuts.

A booster charge is not needed in all burn cuts. As long as the cut holes are breaking in the "clean blasted" zone, and the cut is not overcharged, there should be no need for a booster. If there is an obstruction forming in the cut because of overcharging, too great a spacing between holes, extremely plastic rock, or excessively deep cuts, then a booster might be an aid in cleaning the cut.

In selecting the proper explosive for the booster charge, the first thought is, generally, to use slow-heaving explosives. However, a more critical factor than the explosive action is the explosive's sensitivity. Here again, sympathetic detonation can cause premature firing of the booster charge.

### Theoretical Considerations of the Mechanics of Blasting Rock

Explosive fired within a bore hole is capable of doing work by transmitting energy as a strain wave, which is propagated into the rock by the pressure pulse. In any discussion on breaking of rock with explosives, the question of the mechanics of the rock failure naturally arises. There have been many papers which have discussed this phenomenon in recent years. A large percentage of this work has been performed with explosives fired in air rather than charges confined in a bore hole. Confinement does indeed complicate the picture. Thus, many of the ideas derived are not always completely applicable to blasting rock. Much additional work is needed before

a proven explanation of rock breakage is possible. Still, much good work has been done and generally accepted theories have been developed. A review of the action that theoretically takes place will now be given.

When a column of explosive confined within a bore hole detonates, there immediately arises a peak pressure which initiates the shock wave. The intensity of the wave will be determined largely by the peak pressure rise time, the magnitude and shape of the pressure pulse, and the fall time. These variables are a function of the detonation velocity of the explosive, its density, chemical composition, and degree of confinement. Low-velocity explosive creates weak strain waves, and high-velocity explosive generates very strong strain waves. On this subject, Taylor states:[8]

> The work done by the shock-wave is a very steep function of the velocity of detonation. . . . The shock-wave associated with an explosive may be judged by firing a cartridge vertically on a steel or lead plate, without any stemming or confinement, and seeing what sort of an indentation or hole is formed. . . . A cartridge of blasting gelatin fired at 19,680 f.p.s. will punch a hole right through a 30-mm. lead plate, whereas a permitted explosive firing at 7,216 f.p.s. merely causes an indentation. . . .

While these tests were performed unconfined, they at least indicate varying capabilities of explosives to generate strain waves.

The strain wave generated will propagate outward from the shot hole in all directions in the form of a compression wave. If the amplitude of this compressive wave exceeds the compressive strength of the rock, then there will exist a crushed zone around the shot hole. Brown[9] describes this action thus:

> The very sharp pressure pulse against the walls of the borehole will be propagated through the medium causing brittle failure for a certain distance if the material is brittle, or causing plastic deformation if the material is plastic.

When the amplitude of the compression wave falls below the compressive strength of the rock, the energy will be transmitted as an elastic compressional pulse. As the wave passes into the elastic solid it will form longitudi-

**TABLE II**

**Calculated Explosive Pressure and Detonation Pressure for Various Explosives***

| No. | Explosive | % "C" Nitroglycerin | Density (gm. cc.) | Reaction Stability Pressure (lb./sq. in.) | Explosion Pressure (lb./sq. in.) | Measured V.O.D. (ft./sec.) |
|---|---|---|---|---|---|---|
| 1. | Blasting Gelatin | 91.2 | 1.55 | $27.5 \times 10^5$ | $13.3 \times 10^5$ | 25,500 |
| 2. | Ammon Gelatin Dynamite | 50 | 1.5 | 21.0 | 9.6 | 22,500 |
| 3. | Ammon Gelignite | 32 | 1.5 | 16.0 | — | 19,700 |
| 4. | Permitted Gelatinous 24% NaCl | 27 | 1.55 | 11.0(1)<br>14.0(2) | 5.7 | 19,000 |
| 5. | Permitted Powder 9% NaCl | 10.5 | 0.98 | 5.0(1)<br>6.0(2) | 2.7 | 13,000 |
| 6. | Permitted Powder 35% NaCl | 11.5 | 1.18 | 4.5(1)<br>6.0(2) | — | 12,000 |
| 7. | Lump Coal "CC" Permitted | — | 0.79 | — | 2.9 | 5,500 |
| 8. | 94/6 AN/FO | — | 0.85 | — | 3.1 | 13,800 |

(1) Diluent considered in thermal equilibrium with products.
(2) Diluent considered unheated during the reaction.
*All data except Nos. 7 and 8 after Taylor.[13] No. 7 calculated by author from information supplied by manufacturer. No. 8 from Yancik[14] for 6-in.-diameter hole.

nal and transverse waves. Surface waves (Raleigh & Love) are believed to be of minor significance in the small-scale shot-hole blasting.

The longitudinal waves are frequently called push, or compression, waves because they impart motion to the particles in their path which is in the same direction as the wave propagation. The transverse waves are known as shear waves because they impart motion perpendicular to the path of the waves' advance. The magnitude of the compression wave will be governed by the travel distance of the wave, and by the damping properties of the rock. The longitudinal compression wave moves at a higher velocity than does the transverse wave. Therefore, it reaches any existing free face first. Upon reaching a free face, the compression wave is reflected as a tension wave. If the distance traveled was not so great as to dampen the wave below the critical intensity, and provided that the pulse shape has a rapid decay, the reflected tension wave will cause tension fracturing at the free face surface. As each slab is fractured, it will entrap energy in the form of particle velocity and will thus begin to move away from the solid rock. The intensity of the tension wave will diminish as successive slabs of rock break off and entrap energy, until finally it falls below the tensile strength of the rock. The action of the transverse wave is not well defined. However, it is probable that the shear waves account for a small part of the fracturing in the crushed zone. While it was formerly believed that rock was literally pushed out of place by the expanding gases, the investigations of recent years[10,11,12] show that the principal rock breaking and moving is done by the energy transmitted through wave motion.

To further the understanding of the foregoing description, each of the functions will now be defined quantitatively.

### *The Explosive Pressure*

The explosive pressure is the initial pressure generated by the detonating explosive which acts on the wall of the bore hole. Table II gives the explosive pressures for some of the more common types of explosives.

It is quite apparent that the explosive pressure of the two Permitted Explosives (Nos. 5 and 7) and the AN/FO is far below the range of the other explosives. This factor will be shown to be significant in this paper.

### *Generation of the Strain Wave*

A useful equation for peak strain has been worked out for point charges and the value for the necessary constants has been determined for a few explosives and rock types.[15] The peak strain may be calculated from the following:

$$\epsilon = \frac{K_w}{\lambda} e^{-\alpha \lambda}$$

where $\varepsilon$ = Peak Strain

$\lambda = \frac{R}{W^{1/3}}$ = Scaled Travel Distance

R = Distance

W = Charge Weight

$K_w$ = A Linear Function of the Explosives' Detonation Pressure and the Rocks' Elastic Parameter

$\alpha$ = Absorption Constant for the Rock

In earlier work by Obert and Duvall,[16] they found that greenstone failed at 531 x $10^{-6}$ in./in., owing to dynamic tensile strain of the rock. The static breaking tensile strain of greenstone is 390 x $10^{-6}$ in./in.

From the work of Taylor[8] it was found that high-velocity explosives (above 8,200 f.p.s.) fired unconfined in air were very effective in producing strain waves in hard rock, thus causing fracturing. Explosives that detonated between 8,700 f.p.s. and 5,700 f.p.s. had only the effect of local comminution on the hard rock, while those explosives which detonated below 5,700 f.p.s. had no observable effect.

**TABLE III**

**Propagation Constants (After Duvall and Petkof)**

| Rock | Characteristic Impedance ($\rho c$) | | Explosive | $\left(\frac{\alpha}{\frac{\text{lb.}^{1/3}}{\text{ft.}}}\right)$ | $\left(v \frac{\text{in.}}{\text{in.}} \frac{K_w}{x} \frac{\text{ft.}}{\text{lb.}^{1/3}}\right)$ |
|---|---|---|---|---|---|
| | Rock | Expl. | | | |
| Granite | 54.5 | 26.9 | 80% Straight Dynamite | .0323 | 3400 |
| | | 23.1 | Semigelatin No. 1 | .0428 | 2990 |
| | | 21.1 | Semigelatin No. 2 | .0304 | 2340 |
| Marlstone | 27.1 | 21.1 | Semigelatin No. 2 | .0846 | 4800 |
| Chalk | 22.4 | 21.1 | Semigelatin No. 2 | .0245 | 5250 |
| Shale | 14.5 | 21.1 | Semigelatin No. 2 | .0269 | 5690 |

TABLE IV
**The Calculated Initial Pressure in Medium for Various Explosives Detonated Against Various Rocks**

| Rock | $D_M$ (M/sec.) | Explosive | E | $D_E$ (M/sec.) | $P_M/P_E$ | $P_M$ (p.s.i.) |
|---|---|---|---|---|---|---|
| Triassic Sandstone | 2400 | 60% Straight Dynamite | 1.2 | 5080 | 0.94 | 620,000 |
| Triassic Sandstone | 2400 | Lump Coal CC | 0.79 | 1680 | 1.61 | 472,000 |
| Dolomitic Limestone | 4720 | 60% Straight Dynamite | 1.2 | 5080 | 1.18 | 780,000 |
| Dolomitic Limestone | 4720 | Lump Coal CC | 0.79 | 1680 | 1.81 | 530,000 |
| Rockport Granite | 5100 | 60% Straight Dynamite | 1.2 | 5080 | 1.38 | 910,000 |
| Rockport Granite | 5100 | Lump Coal CC | 0.79 | 1680 | 1.82 | 533,000 |

### *Crushed Zone*

While many authors have discussed the crushed zone surrounding a shot hole, few have reported the dimensions of the zone. From the experimental work of Obert and Duvall[16] comes a formula which defines the radius of cavity (A) as $A = K\sqrt[3]{W}$ where W is the charge size (in lb.), and K is an experimentally determined constant which is a function of the frequency and velocity of the propagation wave and the compressive strength of the rock. In the case of their experimental work, they determined K to equal 0.89. They used 1¼ by 8-in. cartridges (approximately ½ lb. each) of 60% ammonia gelatin. Their rock was greenstone, which has an average compressive strength of 44,200 p.s.i. Therefore, the cavity radius for a ½-lb. charge of one cartridge,

$a = 0.89\sqrt[3]{0.5} = 0.706$ ft. or 8.47 in.

### *Acoustic Impedance*

The average rate of flow of energy through a medium is governed by the acoustic impedance. This form of resistance is the product of $\rho c$, $\rho$ being the density of the material, and c being the velocity of sound in the medium. As an example, the average $\rho$ of the Bonneterre dolomitic limestone is 175 lb./ft.$^3$. Obert[17] reports the velocity of sound in this rock as 15,480 f.p.s. Therefore, the acoustic impedance would be 48.6 lb./sec./in.$^3$. Compare this with those values given in Table III. Dr. Brown[9] demonstrates how the values of the acoustic impedance of the explosive gases may be compared to that of the rock and a performance parameter developed therefrom. He states:

> The acoustic impedance of the explosive and the medium determine the magnitude of the initial maximum pressure in the pressure pulse in the medium. If an explosive of density, $\rho_E$, velocity of detonation, $D_E$, and detonation pressure $P_E$ is detonated against a medium of density $\rho_M$ in which the velocity of shock is $D_M$; the initial pressure, $P_M$, in the medium will be given by

$$\frac{P_M}{P_E} = \frac{2}{1 + \frac{\rho_E D_E}{\rho_M D_M}}$$

Using Brown's formula, the values of $P_M/P_E$ were tabulated for three different rocks and two different explosives and are presented in Table IV. Notice that the $P_M/P_E$ values of the Lump Coal are consistently higher than for the faster 60% straight dynamite. This brings out the importance of the impulse of the slower explosive, and how the acoustic impedances of the two media affect it. However, one cannot ignore the explosive pressure which also helps determine the impulse, and, in turn, determines $P_M$. These two parameters, the explosive pressure and the acoustic impedance, are then the best measures of the impulse imparted to the rock by the shock wave.

### *Specific Damping Capacity*

The absorption of energy from the pressure pulse as the wave moves through the rock is governed by the damping properties of the rocks. This is known as the specific damping capacity of the material, which is the ratio of the energy dissipated per cycle of vibration to the total vibrational energy. The following table gives the approximate range of values as reported by Blair[18] and Windes.[19]

TABLE V
**Approximate Range of Specific Damping Capacity**

| | |
|---|---|
| Sandstone | 1000 - 1700 |
| Shale | 1300 - 1500 |
| Limestone | 200 - 2000 |
| Granite Gneisses | 300 - 800 |
| Granite | 200 - 600 |

As would be expected, the sedimentary rocks in general have higher damping capacity than others. Also, the value of the damping capacity of most of the rock is fairly consistent, with the exception of limestone. This is due to the inconsistent nature of limestone, which may be very dense, medium hard stone or a chalky soft limestone. Within the Bonneterre dolomitic limestone formation, the specific damping capacity is reported to range from 200 to 1,100.

### *Tension Slabbing*

As the dampened shock wave reaches the free face, it is reflected as a tension wave. If the tensile strength of the rock is considerably less than the compressive strength, fracturing will start when the magnitude of the tensile wave equals the tensile strength of the rock. Thus a slab will form and entrap a portion of the original compressive shock wave, giving the slab momentum. As there is a new free face formed, the remaining shock wave will again be reflected and the slabbing

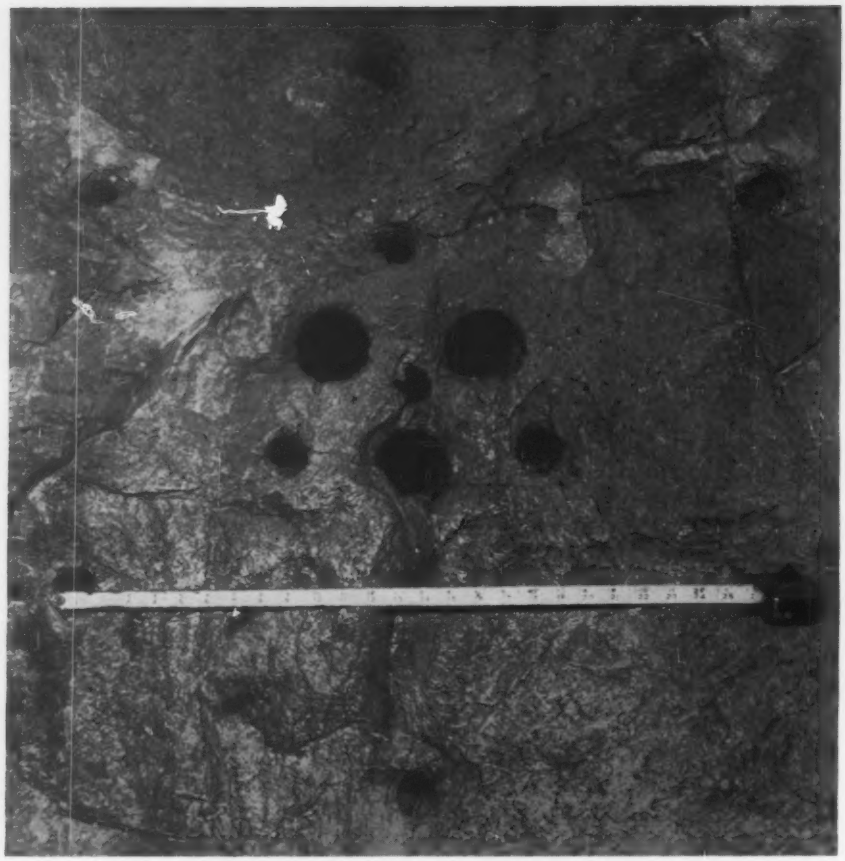


**FIGURE 4: This burn-cut pattern was evolved from the investigations described in this article. It is currently being used as the cut pattern for all the rock breaking at St. Joseph Lead Company's Viburnum mines.**

process repeated. This will continue until the remaining reflected tensile wave is too weak to cause tension failure in the rock. Hino,[11] from his work on unconfined charges, defines the thickness and the number of the slabs by the following equations:

$$T = \frac{L}{2}\frac{S_t}{P_a}$$

$$N = \frac{L}{2T} = \frac{P_a}{S_t}$$

$T$ = Slab Thickness

$L$ = Shock Wave Length

$S_t$ = Tensile Strength of the Rock

$P_a$ = Peak Pressure of Shock Wave at the Free Face

$N$ = Number of Slabs

The maximum distance from the shot hole to the free face may be cal-

**TABLE VI**

**Maximum Hole Spacing for Various Explosives and Rocks***

| Rock | Ultimate Tensile Strength (p.s.i.) | Critical Radius: Inches per inch of charge cartridge diameter. | | | | | |
|---|---|---|---|---|---|---|---|
| Explosive Type (Ref. Table II) | | 1 | 2 | 3 | 4 | 5 | 6 |
| Granite: | | | | | | | |
| Strong | 1,288 | 37 | 32 | 28 | 25 | 16 | 16 |
| Average | 888 | 45 | 39 | 34 | 30 | 20 | 19 |
| Weak | 422 | 65 | 56 | 49 | 43 | 29 | 28 |
| Limestone: | | | | | | | |
| Strong | 890 | 45 | 39 | 34 | 30 | 20 | 19 |
| Average | 480 | 61 | 53 | 46 | 41 | 27 | 26 |
| Weak | 280 | 79 | 69 | 60 | 53 | 35 | 35 |
| Sandstone: | | | | | | | |
| Strong: | 583 | 55 | 48 | 42 | 37 | 24 | 24 |
| Average | 412 | 65 | 67 | 50 | 44 | 29 | 28 |
| Weak | 280 | 79 | 69 | 60 | 53 | 35 | 35 |
| Anhydrite: | | | | | | | |
| Strong | 1,220 | 38 | 33 | 29 | 25 | 17 | 17 |
| Weak | 800 | 47 | 41 | 36 | 32 | 21 | 20 |

*After Pearse

**TABLE VII**

**Statistical Data for Burn-Cut Drift Rounds[22]**

| Figure No. | Type of Rock | Area (sq. ft.) | Advance Per Round (ft.) | Volume (cu. yd.) | No. of Holes | Drilling Footage | Drilling Footage Per cu. yd. | Explosive Consumption (lb./cu. yd.) |
|---|---|---|---|---|---|---|---|---|
| A | Granite | 48 | 9.7 | 17.3 | 21 | 220 | 12.7 | 5.5 |
| B | Granite | 43 | 9.5 | 15.2 | 30 | 315 | 20.7 | 9.45 |
| C | Granite | 43 | 6.9 | 11.0 | 24 | 187 | 17 | 7.1 |
| D | Granite | 43 | 6.6 | 10.4 | 27 | 190 | 18.2 | 6.8 |
| E | Granite | 128.6 | 5.9 | 28.3 | 47 | 302.5 | 10.7 | 3.2 |
| F | Quartz | 52.2 | 4.4 | 8.6 | 34 | 161.7 | 18.8 | 7.1 |
| G | Schist | 64 | 9 | 21.4 | 35 | 315 | 14.7 | 4.86 |
| H | Meta-Ls | 72 | 10 | 26.8 | 31 | 310 | 11.6 | – |
| I | Meta-Ls | 64 | 7 | 16.6 | 31 | 217 | 13.1 | 5.10 |
| J | Dolom-Ls | 45.5 | 5.0 | 8.4 | 25 | 125 | 14.9 | 5.35 |
| K | Dolom-Ls | 60 | 14.5 | 32.2 | 21 | 290 | 9.0 | 5.23 |
| L | Ls | 42 | 7.5 | 11.7 | 22 | 176 | 15.1 | 8.43 |
| M | Shale & Ss | 133 | 11 | 54.2 | 51 | 612 | 11.3 | 6.3 |
| N | – | 114 | 8.5 | 35.9 | 37 | 314 | 8.75 | – |
| O | Ls | 527 | 12.0 | 234 | 63 | 756 | 3.23 | 1.92 |

culated with reasonable accuracy from the work of G. E. Pearse.[20] He developed the formula:

$$R = KD\frac{P_s}{S}$$

where: K = Constant (about 0.8 for most rocks)
D = Charge Diameter (in.)
$P_s$ = Detonation Stability Reaction Pressure (Table II)
S = Ultimate Tensile Strength of the Rock
R = Critical Radius or "Burden" (in.)

Using K as 0.8 and $P_s$ as given in Table II, Pearse tabulated the information given in Table VI. He then checked the values of anhydrite by experimentation and found them to compare remarkably well.

***Theoretical Consideration of the Rock Failure in the Burn Cut Developed at St. Joe***

While the foregoing theories may hold true for nearly all cases of blasting rock, it is the author's opinion that there may be cases that are exceptions. For example, in the experimental work covered in this report, evidence was found which shows that a burn cut breaks in a different manner.

The shatter cut that was finally developed and is now being used in the newer mines of St. Joe is shown in Figure 4. As in any burn cut, the free faces to which the loaded holes break are the unloaded holes of the cut. Several different explosives were tried in the loaded holes of the cut. The detonation velocities of the explosives tried were: 12,600 f.p.s., 9,000 f.p.s., 6,500 f.p.s., and 5,500 f.p.s. In the early stages of testing, the distance between the loaded holes and the large open holes was varied in order to design a shatter cut that would function properly. When the charged holes were at too great a distance from the open holes to give a clean break, they filled the open holes with recompacted rock. As the distance was increased, the loaded holes would bootleg, but they would not break any rock from the wall of the open hole. From the above observation, it would seem that tension slabbing is not causing the failure. If it were, then there would be a critical "loaded hole to open hole distance," at which there would be some rock broken from the wall of the open hole without causing failure between the holes.

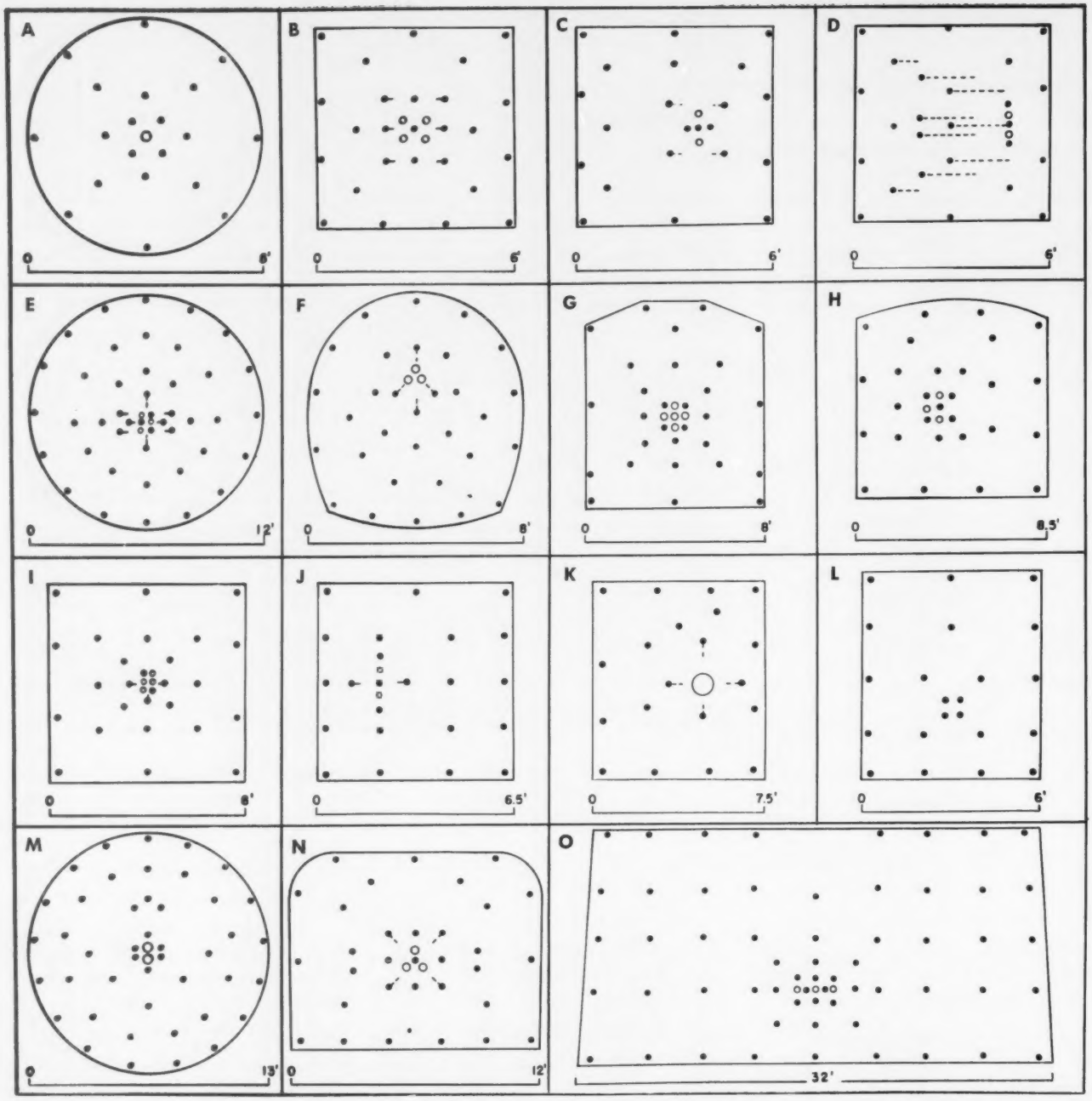



**FIGURE 5: Some examples of typical burn-cuts used in drift rounds. Performance figures for the various rounds are given in Table VII.**

It seems that there must be another explanation of the failure. Yancik and Clark,[4] when discussing the tension slabbing theory, state:

> Applied to a large hole burn cut, a compressive wave . . . is transmitted radially from the blast hole and is reflected from the surface of the large hole. According to the laws of reflection, a tensile wave would assume a path more convex than the incident wave. In being reflected from a cylindrical (convex) interface, the wave energy is dispersed much more rapidly than it would be from a plane or concave interface.

This being true, then the smaller the open hole, the faster the energy would be dispersed until, finally, at some critical hole size, such a boundary condition would exist that it would, in all probability, prevent tension slabbing of the free face. In the shatter cuts tested, the open hole size was varied from 2½ to 4 in. It is the author's opinion that such a boundary condition did exist in the tests performed. The question then arises as to how the rock does fail.

One hypothesis is that the rock fails by shearing between the loaded hole and the unloaded hole. The mechanics of this failure was best demonstrated by Rinehart and Pearson.[21] They detonated an explosive layer ⅛ in. thick on the surface of a 2¾-in. O.D. aluminum cylinder which had a ¾-in. hole through the longitudinal axis of it.

As the strain wave moved toward the relief hole, it developed two correlative orthegonal trajectories of maximum shear stress at each point in the cylinder. These trajectories spread out in continuous curved lines from points on the surface of the relief hole where the shear stress was at a maximum. It seems evident from this work that the primary fracturing around a relief hole such as that in a burn cut is due to the shear stresses developed around the hole.

Another observation is that when the higher velocity explosives were used in the loaded holes, the cut failed to break clean. This resulted in recompacted rock filling the open holes. When the cut failed in this manner, there was observed a crushed zone in the position previously occupied by the loaded holes. It was usually about 2½ to 3½ in. in diameter. When, on one occasion, the cut did break successfully with the high-velocity explosive, there existed no crushed zone.

On the other hand, when the low-velocity explosives were used, the cut did break properly and cleaned itself of broken rock, but left no crushed zone around the loaded holes. The only time that the cut failed with the low-velocity explosive was when the holes were fired instantaneously rather than one at a time. Even then, there existed no crushed zone around the loaded holes.

If the theories presented in the previous discussion on crushed zones were to hold true, then there should be a crushed zone in every case whether or not the cut failed to break clean. Obviously, this is not the case for the tests performed. The answer probably lies in the fact that for the rock of the Bonneterre formation, a high-velocity explosive as well as a high charging density is needed to create a crushed zone.

(EDITOR'S NOTE: *The original work on which this article is based was published in the Third Annual Symposium on Mining Research, University of Missouri School of Mines and Metallurgy, No. 95, 1958. Part II of this two-part article will appear in the March-April issue of* THE EXPLOSIVES ENGINEER.)

### Types of Burn Cuts

The types of burn-cut patterns that have been successfully employed throughout the world are practically unlimited. Every conceivable geometrical pattern, with varying relief hole sizes, has been tried. Space does not permit a description of the various types of burn cuts; however, there are many published articles where they can be found.[3,6,22,23]

Examples of how some of the typical cuts have been employed in drift rounds are given in Figure 5. Table VII summarizes the performance figures for the various rounds.[22]

## REFERENCES


[1]Bruce D. Jones, "Rock Tunneling for Underground Protective Construction," *Quarterly of the Colorado School of Mines*, Vol. 46, No. 1, 1951.

[2]John G. Hall, "Blasting a Burn-Cut Round in a Drift," THE EXPLOSIVES ENGINEER, July-August, 1948.

[3]E. Steidle, "Some Practical and Theoretical Aspects of the Burn Cut," Joy Manufacturing Co., Pittsburgh, Pa.

[4]J. J. Yancik and G. B. Clark, "Experimentation with Large Hole Burn Cut Drift Rounds," *Bulletin No. 93*, Univ. of Mo. School of Mines, 1956.

[5]C. H. Noren and L. E. Shaffer, "The Influence of Cartridge Diameter on the Effectiveness of Dynamite," *Univ. of Mo. School of Mines Bulletin*, Vol. 19, No. 1, 1948.

[6]Ulf Langefors, "Principles of Tunnel Blasting," Part I, *Water Power*, London, Jan., 1955.

[7]Ulf Langefors, "New Raising Methods," Parts I and II, *Mine and Quarry Engineering*, Vol. 23, Nos. 8 and 9, London, Aug. and Sept., 1957.

[8]James Taylor, "The Mechanism of Blasting of Coal and Rock by Means of Explosive," *Trans. of The Institute of Mining Engineers*, Vol. 108, 1934.

[9]F. W. Brown, "Determination of Basic Performance Properties of Blasting Explosives," Symposium on Rock Mechanics, *Quarterly of the Colorado School of Mines*, Vol. 51, No. 3, July, 1956.

[10]C. W. Livingston, "Fundamental Concept of Rock Failure," Symposium on Rock Mechanics, *Quarterly of the Colorado School of Mines*, Vol. 51, No. 3, July, 1956.

[11]Kumao Hino, "Fragmentation of Rock Through Blasting," Symposium on Rock Mechanics, *Quarterly of the Colorado School of Mines*, Vol. 51, No. 3, July, 1956.

[12]M. A. Cook, *The Science of High Explosives*, Reinhold Publishing Corp., N. Y., 1958.

[13]J. Taylor, *Detonation in Condensed Explosives*, London, Oxford University Press, 1952.

[14]J. J. Yancik, R. F. Bruzewski, and G. B. Clark, "Some Detonation Properties of Ammonium Nitrate," *Fifth Annual Symposium on Mining Research*, Bulletin No. 98, Univ. of Mo. School of Mines, 1959.

[15]W. I. Duvall and B. Petkof, "Spherical Propagation of Explosion-Generated Strain Pulses in Rock," R. I. 5483, U.S.B.M., 1959.

[16]L. Obert and W. I. Duvall, "Generation and Propagation of Strain Waves in Rock," Part I, R.I. 4683, U.S.B.M., 1950.

[17]Leonard Obert, "Measurement of Pressure on Rock Pillars in Underground Mines," Part III, R.I. 3521, U.S.B.M., 1940.

[18]B. E. Blair, "Physical Properties of Mine Rock," Part III, R.I. 5130, 1955.

[19]S. L. Windes, "Physical Properties of Mine Rock," Part I, R.I. 4459, and Part II, R.I. 4727, U.S.B.M., 1949-1950.

[20]G. E. Pearse, "Rock Blasting, Some Aspects on the Theory and Practice," *Mine and Quarry Engineering*, Jan., 1955.

[21]J. S. Rinehart and J. Pearson, *Behavior of Metals Under Impulsive Loads*, Cleveland, Ohio, American Society of Metals, 1954.

[22]R. L. Bullock, "Fundamental Research on Burn Cut Drift Round," *Third Annual Symposium on Mining Research*, Bulletin No. 95, Univ. of Mo. School of Mines, 1959.

[23]K. H. Fraenkel, "Factors Influencing Blasting Results," *Manual on Rock Blasting*, Atlas Diesel and Sanviken Iron Works, Stockholm, 1952.

# Hanna's Pierce Mine

**Since the discovery of iron ore in the Mesabi in 1887, the range has undergone constant change. The Pierce Mine is one of the latest developments in this fabulous area**

L. H. HOUCK*

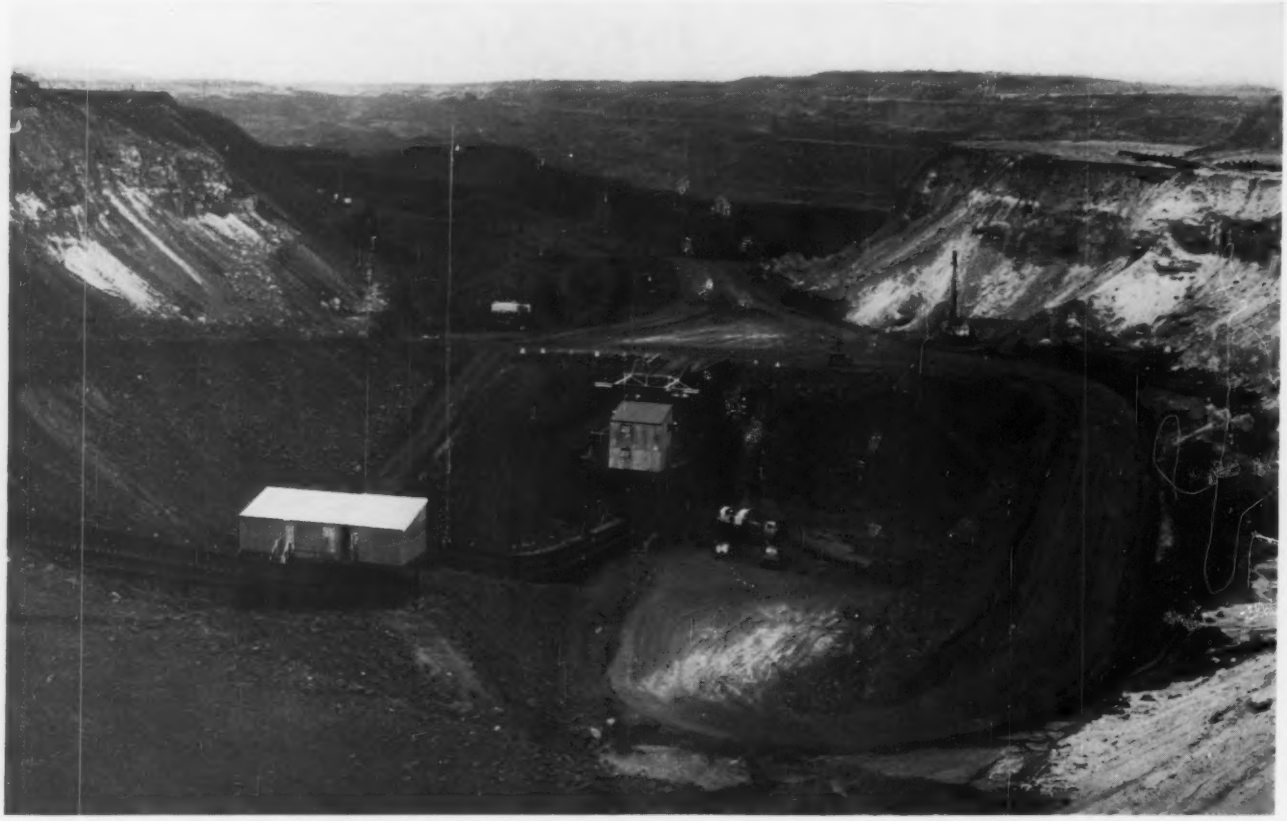
MESABI, a synonym for iron ore all over the world, is a range of low hills that lie southeast of some higher elevations called the Giant's Range, about 65 miles northwest of Duluth, Minnesota, on Lake Superior. Mesabi is one of a trio of Minnesota iron ranges; its companions are the Vermilion, between Vermilion Lake and Ely, and the Cuyuna, between Brainerd and Aitkin. The first ore shipped from the Mesabi Iron Range was loaded in 1892.

Iron ore was discovered in the Mesabi in 1887 by Leonidas Merritt and his brothers. The Merritts established claims to parts of the area in 1890 and organized the first mining company on the range to exploit the ore. In 1893 John D. Rockefeller acquired control of the company.

Since the ore here is found in nearly horizontal layers instead of vertical strata, the formation proved ideal for the development of strip mining. The Mesabi Iron Range has become not only the largest strip mine area in the world but is famous as a pioneer of this type of mining.

The largest iron ore pit is 3¼ miles long, one-half to a mile wide, over 500 ft. deep, and covers an area of 1,561 acres. This pit is widely known as the Hull-Rust-Mahoning open-pit iron

*400 Linden Drive
Jefferson City, Missouri



**PANORAMA: From the photographer's vantage point one gains an excellent view of the mine, the primary crusher, and part of the conveyor system and a haul road that serves the Pierce Mine.**

mine, but it embraces such well-known mines as the Hull-Rust, Sellers, Penobscot, Susquehanna, Webb, Agnew, Kerr, Mahoning, Scranton, Weggum & Boeing, and now a new extension known as the Pierce Mine.

Since the discovery of iron ore in the range the Mesabi has never stood still. Operations are being constantly improved, and nothing has ever been able to withstand the ever-reaching teeth of the shovels.

### Progressive Expansion

The new Pierce Mine of the Hanna Ore Mining Company, M. A. Hanna Company, Agents, of Cleveland, Ohio, is an outstanding example of the progressive expansion and growth of the area. The Pierce includes the Nordac, Impro B, and Roy properties, part of which were the original site of the village of Hibbing. There are about 10 million tons of iron ore available in these properties for mining, beneficiation, and shipment. It is estimated that the life of the mine will be about 15 years.

When the mining town of Hibbing, Minnesota, was established in 1893, the town planners probably didn't know that the town site was laid out on top of a rich bed of iron ore. With the machinery and methods of the "gay 90's," they could not have visualized the future proportions of the demand for iron and steel, nor the great open pit, much less the dragline strippers and rock-loading shovels.

By 1917 Hibbing was besieged on three sides by mines, and it was decided to move the town 2 miles south in order to release the iron ore beneath the streets and buildings. At that time, the population of Hibbing was about 9,000.

Moving a town, even a small town, is a sizable job and not one to be accomplished overnight. The moving operations reached their peak in 1918 when entire buildings were jacked up and moved to the new location. Some of the larger structures were cut into two and three sections. The present business section of Hibbing was started about this time. But the move left Hibbing in two sections: South Hibbing and North Hibbing.

**DRILLING AND CLEANUP: The work of drilling holes for the next blast goes on as an electrically powered 8-yd. shovel cleans up the well-broken ore from a previous blast. The 7½-in. holes are drilled 33 ft. deep on an 18 by 18-ft. pattern.**

**LOADING: The average wet blast hole drilled 33 ft. deep will require 250 lb. of Dynatex B-WR packed in 6½-in. 30-lb. cartridges. Plastic wire-countered Primacord and millisecond Primacord connectors are used to detonate the blasts.**

**DRAGLINE AT WORK: Overburden is stripped by this Bucyrus-Erie dragline with its 30-yd. bucket. The material is dumped into a portable screening plant and then to a conveyor for transportation to a spoil area 3 miles distant.**

### Final Moving Plans

The final phase of the move did not come until 38 years later. In 1956, Hibbing residents voted to permit the sale of all remaining public building and facilities in North Hibbing to mining companies. This action made it possible to abandon streets, sidewalks, water and sewage lines, street lighting, and public buildings.

The M. A. Hanna Company, one of the large operators in the district, had already acquired the properties now known as the Pierce Mine and had completed an extensive exploration program by drilling. Its next move was to "walk" a huge Bucyrus-Erie 1150-B, 30-cu. yd. dragline, with a 180-ft. boom, from its Morton Mine, 4 miles away, to the new mining site. This was done in the spring of 1957. The move had to be made before the ground thawed so that the 1,200-ton stripper would have support.

Moving this machine 4 miles through a mining district was a historic event and required construction of the equivalent of a four-lane highway. The route lay between the Morton and the Norpac Mine properties. Since this movement was across the busy ore-transportation routes over stripping dumps, and through operating properties, it had to be completed before the ore-shipping season opened. Some idea of the complications in getting the big stripper to the new location at the Pierce Mine site may be gleaned from the fact that the job required dozens of men, seven 34-ton trucks, six bulldozers, two cranes, much auxiliary equipment, and took 18 days.

The dragline is electrically powered. Its 3,000-KVA transformer, used at the Morton Mine, was mounted on a trailer and its primary hooked into 23,000-volt lines along the route. About a half dozen hookups were made during the journey.

Moved along with the dragline was the 540-ton portable screening plant and the conveyor system. Used exclusively for stripping surface overburden from the ore beds, this 1150-B Bucyrus-Erie arrived on the Mesabi Iron Range in 1947 and was assembled at the South Agnew Mine. Lloyd Bredvold, who formerly was superintendent of the South Agnew and Morton Mines, is now superintendent of the Pierce Mine and its ore concentration plant. At the time it was moved, the big machine had stripped more than 40 million tons at its normal rate of 1,000 cu. yd. per hour. But unlike the situation encountered at the Morton, where it stripped for 4½ years before a ton of ore was shipped, the shipments of ore from the Pierce Mine got under way during the 1960 season.

Overburden must be stripped in advance of the mining operation, and the dragline dumps its 30-yd. buckets of spoil into the hopper of a portable screening plant which delivers minus 9-in. material to a 48-in.-wide belt conveyor. This transports the waste to spoil dumps 3 miles from the mine proper.

### Drilling and Blasting

Once the iron formation is exposed, drilling and powder crews move in along with the rock-loading shovels. Blast-hole drilling is done with a 40-R Bucyrus-Erie blast-hole drill, electrically powered, with a "down-in-the-hole" bit drilling a 7⅞-in. hole 33 ft. deep on an 18 by 18-ft. pattern. The rig drills an average of 250 ft. of hole per shift. The same machine is used for rotary drilling of 9-in. holes when advantageous.

The ore beds encountered vary from high-grade direct-shipping ores to low-grade ores requiring all of the treating facilities at the concentrating mill; these ore layers are usually separated by slaty and cherty taconite and by a paint rock layer, which is near the bottom of the ore deposit.

A wet blast hole is loaded with 250 lb. of Dynatex® B-WR nitro carbo nitrate in 6½-in. 30-lb. cartridges. Ammonium nitrate and fuel oil are used in dry holes, which make up the bulk of the blasting. Hole spacing, depths of holes, and explosive charge will vary with the types of material to be blasted.

Plastic wire-countered Primacord* detonating fuse is used, because this type of covering offers greatest resistance to abrasion. Millisecond delay Primacord connectors complete the setup.

A variable number of holes are loaded and detonated at a time because of the nearness in some locations of other workings. Usually a blast consists of 8 to 10 holes, and blasting is done once a day. Average break in this formation is about 400 cu. yd. per hole, or a powder factor of 0.62 lb. of explosive to one cu. yd. of material.

### Geology of Area

Twenty-two miles of railroad track traverse the "Hull-Rust-Mahoning" pit, from which almost 500 million tons of waste material were moved between 1895 and 1960. More than 550 million tons of iron ore have been shipped out of the pit to date. The localization of such great quantities of iron ore in the Mesabi Range is almost incredible. The Mesabi has long been the world's greatest source of iron ore, and for many years it produced more than one-third of the world's supply. How this happened makes a fascinating story. It is one of the most exciting and dramatic geological episodes in the vast million-year stretches of geologic time.

Pieced together by years of study by geologists, it shows that first came great outpourings of lava that formed the Ely greenstones, the most ancient rock in the world. This formation of the oldest existing rock and metamorphous lavas is exposed over large areas of the Mesabi region between Virginia, Eveleth, and Gilbert.

The next occurrence was the deposition of great thicknesses of mud and sands, and these sediments, along with volcanic ash and other materials, became cemented and compacted into the Knife Lake slates, more than 5,000 ft. thick. These rocks were intensely folded and the folds deeply eroded.

Then came the intrusion of the Giant's Range granite batholith and its associated igneous rocks. The mass of magma (molten rock below the surface) that formed this granite was intruded into the Knife Lake slates and older formations at great depths beneath the surface of the earth. At this geological time, the slates were thrust upward into a great system of folds now called the Algoman Mountains. This period is sometimes referred to as the Algoman interval.

To wrap up some of the succeeding millions of years in a small package, there was a tremendously long period of erosion. Then a sea of the Animikean period covered the region and deposited sand and gravel that formed the Pokegama quartzite. The sea eventually cleared

*Reg. U. S. Pat. Off. by The Ensign-Bickford Company

**IN THE PIT: The blasted crude ore is transported by a fleet of Euclid and Mack trucks of 34- and 40-ton capacity.**

and new chemical elements were precipitated and deposited to form the Biwabik iron-bearing formation, from the iron and silica in solution in the waters of this inland sea.

The minerals became enmeshed in a matrix of fine-grained silica, deposited as a gelatinous mass, which became consolidated in a rock known as chert. Chert, specifically, is a compact gray form of crystallized quartz. Flint is essentially the same substance.

The sea retreated, another period of erosion followed, and then came the lava flows in northeastern Minnesota and the intrusion of Duluth gabbro.

While the center of the earth is supposed to be largely iron and nickel and since it is also supposed that much of our iron ore in commercial quantities comes from the same source, the fact remains that iron ore ranging from minute quantities to huge deposits is present in almost all the formations of the country. This makes it all the stranger that such large quantities should be concentrated in the Minnesota iron ranges and proves again that certain things must happen in an orderly sequence to make it possible.

### Ore Deposit

Our iron ore at the period of geological development is still pretty much mixed with other materials and far from its present concentrated state. So the next event is of great importance.

At a relatively early time during this period, the Biwabik formation was exposed on the earth's surface by erosion, and at favorable locations where water could circulate through it. Much of the silica was leached out, leaving concentrations of iron oxides that are essentially the iron ores mined today. The only later covering was the glacial drift that formed some 100 ft. of overburden, which is now being removed to expose the ore-bearing layers.

The wide color differences of the iron ore in this district, evident to all, are due to variations in mineral composition of the ore. These variations are related to differences in the character of the rock from which the ore is derived. In other words, when the ore was deposited, the forces did not pick the rocks but pressured it into whatever was at hand.

The Biwabik formation is not of uniform composition throughout its entire thickness. The average composition is as follows:

| | |
|---|---|
| Iron | 25.71% |
| Silica | 58.70 |
| Aluminum oxide | 0.54 |
| Phosphorus | 1.96 |
| Other chemicals | 13.09 |
| | 100.00% |

Some parts of the formation are thinly bedded and break easily, thus earning the name of slaty taconite. Other formations are composed of massive, thick-bedded chert, producing cherty taconite. Bright red and bright yellow ores come from the slate of the formation, whereas the dark brown and bluish-black ores represent massive chert.

### Hauling Procedure

The blasted crude ore at the Pierce

HAULAGE ROAD: The well-maintained haulage roads in the Pierce Mine are conducive to the quick transport of the crude ore from blast areas to the primary crusher.

**A BIG ONE: The 60-ton-capacity haulage truck was built by Unit Rig and Equipment Company to meet Hanna's requirements. The truck, powered by a diesel-electric system, is now undergoing tests at the Pierce Mine.**

is loaded into a fleet of Euclid and Mack trucks, 34- and 40-ton capacity, by electric-powered shovels, either an 8-yd. P & H or an 8-yd. 190-B Bucyrus-Erie. A second 190-B Bucyrus-Erie was recently erected and put in use. There is also a 71-B 3-yd. shovel used as a utility machine and a P & H 35-ton crane.

The truck fleet delivers to a pit screening plant which includes a 42 by 48-in. Pioneer primary jaw crusher fed by a 5 by 16-ft. apron feeder. Oversize ore can be crushed or rejected; rejected rock is hauled to the dump. The product of the screening and crushing plant, reduced to minus 5 in., goes to a 48-in. conveyor belt for transportation out of the pit and is deposited in selected piles by a radial stacker at the delivery end on surface.

Separation and stacking of crushed ore are determined by chemical analysis. Ore that requires no further milling and which is ready for direct shipment to the steel mills goes from the radial stacker to a direct overhead loading bin into railroad cars.

### Milling

Ore destined for the mill is dumped by the radial stacker into two 20,000-ton surge piles. Underground feeders and conveyors draw this ore to the concentration plant. The crude ore flows into the new concentration plant, where water is added. The ore flows over a primary screen, with oversize from the screen going to gyratory crushers; undersized and crushed material goes to the scrubber section. Eventually the water and free silica are removed, leaving various grades of ore ready for shipment or further beneficiation.

Hanna's new mill has a feed capacity of 800 tons per hour. It is an all-electric mill with several automated and electronic features not hitherto used in such a plant and still in the process of development and perfection.

Actually, the new plant is four plants in one. The first section is a washing and scrubbing plant; the second section, a spiral plant; the third section, a cyclone plant; and the fourth unit is a heavy-density plant. Since there are separate surge piles to feed the heavy-media and cyclone section, these units may be operated independently. This permits shutdown of a section for maintenance work while the rest of the plant operates.

The mill uses immense quantities of water and, even in this land of lakes noted for the abundance of water, obtaining enough water proved one of the problems. Water collected by pumps from lower areas was piped into a 280-acre lake for half a year. This water is supplied to the mill by two electric vertical pumps, each with a capacity of 6,000 g.p.m., making a total of 12,000 g.p.m., which is

**KEY MEN: Lloyd Bredvold, shown at the left, is superintendent of the Pierce Mine, and Milton Englund is assistant superintendent.**

required to operate the mill. The water is recirculated, with the 280-acre pond so constructed that after settlement of tailing, the clear water flows to a connected pond from which the pumps return the water to the plant. Pumps are operated from the mill's extensive electric control board by a radio carrier wave superimposed on the power line.

Other facilities of the mine include an office, truck repair shop, welding and machine shop in a 90 by 220-ft. building, part of which is two stories.

Because of the comparatively short shipping season and the severe winters of the region, capacity and efficiency of such a mining operation must be geared to approximately a six months' period, which starts the latter part of April and usually ends by October 25. When the Great Lakes freeze over in the fall, the ore boats that transport most of the ore are docked until spring.

At the Pierce Mine, the concentration plant operates 24 hours a day, and the mining shifts work two or three 8-hour shifts as required. All of the ore goes by rail from the mine to Superior, Wisconsin, where it is loaded into the boats on Lake Superior for water transportation to the steel production centers. The mine usually works more than the six months' period, with stripping going forward through the winter months. Maintenance and shop crews overhaul machinery and equipment, and building of new facilities may be accomplished.

As mentioned previously, Lloyd Bredvold is in charge of the Pierce Mine operation. Milton (Swede) Englund is assistant superintendent. Emory Menozzi is general pit foreman for ore production, and Robert Sarago is general pit foreman for stripping during this period of rapid mine development.

**CONVEYORS: Extensive use is made of conveyors at the Pierce Mine. The feed belt at the right of the photo conveys ore from the primary crusher and screening plant to the radial stacker.**

# THE MOLES AWARDS

## Harry T. Immerman and Herman Brown are awarded plaques and citations for their outstanding contributions to the heavy-construction industry

When The Moles, one of the oldest associations of heavy-construction men, convened for their Annual Awards Dinner on January 25 at the Waldorf-Astoria Hotel in New York City, they honored two men, Harry T. Immerman and Herman Brown, who have long been identified as leaders in this field.

The 1961 Awardees are the twenty-first pair to receive the bronze plaques and citations given annually by The Moles to one member and one nonmember for "outstanding achievement in heavy construction." Mr. Immerman is vice president and chief engineer of Spencer, White & Prentis, Inc., of New York City, and Herman Brown is president of Brown & Root, Inc., of Houston, Texas.

HARRY T. IMMERMAN

HERMAN BROWN

MR. IMMERMAN, the member recipient and a native of New York City, is vice president and chief engineer of Spencer, White & Prentis, Inc., having joined that company in 1923. In earlier associations he was chief engineer for the building of the Lewisohn Stadium of City College of New York, and designed and supervised installation in the Times Square area of the first all-steel subway decking system in New York. He has been called upon several times by the City of New York for expert testimony on foundation, underpinning, and shoring problems.

Mr. Immerman has served as consultant to many industrial organizations. He has had numerous articles published in technical journals, and has lectured in various engineering schools on these matters.

MR. BROWN, the nonmember recipient, is a native of Belton, Texas, and is president of Brown & Root, Inc., a Houston enterprise that has grown out of a company he founded in 1914, shortly after his graduation from the University of Texas. The company has been responsible for more than $2 billion worth of construction projects throughout the world. Mr. Brown has organized associate companies in the fields of engineering, marine operations, securities, railway equipment, and gravel so that the parent company can have, as he describes it, "unified responsibility for engineering, design, and construction."

Mr. Brown is an officer or director, or both, of companies engaged in banking, oil, steel, pipelines, equipment, transport, mining, gravel, and marine operations.

# Novel Method For Blasting Earth-Covered Rock

**The deepening of the Lindö Canal leading to the Swedish port of Norrköping was made feasible by the "Lindö" method of drilling and blasting**

J. GRINDROD*

DRILL RIG: With a 52-ft. feed, these machines can drill down to 65 ft. Frames of I-beams and tracks of steel sheet piling provide for longitudinal and transverse movement over the drilling area. Specially designed crown bits were used on these machines.

A unique excavating and blasting method, the result of ten years of experimental work and the collaboration of four Swedish industries, was used in excavating a new outlet from the harbor of Norrköping, on the Central Swedish east coast. Featuring several interesting innovations, it enables blasting into the bedrock to be performed without previous excavation of the covering layers of moraine, clay, and earth. What is claimed to be the world's largest delayed-interval blast, by virtue of the number of holes drilled, was recently detonated at this site by means of this method.

Named the "Lindö" method after the name of the canal that was then being excavated, the new system is based on the Atlas Copco compressed air method with series detonations. The system differs from the normal system in that the rock-steel proper is surrounded by a steel tube equipped with a circular crown bit, used to prevent loose matter from caving in when the bit is being removed. The steel, which protrudes about an inch from the tube, works in conjunction with the tube, and when both have a firm grip (about 4 in.) on the rock bottom, the tube is disconnected from the drilling movement, while the inner bit continues boring into the rock to the desired depth. When the bit is withdrawn, the tube constitutes the connection between the surface and the rock.

### Steel Tube Replaced

So as not to destroy the expensive

*Maiwand
48 Gore Road
New Milton, Hants., England

steel tube and its crown in the blast, it is replaced by a plastic tube, through which water and air are first flushed to clear the hole. The priming and remaining charges are then inserted through the plastic tube by means of compressed air, which makes possible a great savings in time and manpower. The dynamite cartridges are inserted in the breech of the compressed-air loader, and are pushed in until they begin to stick. They are then eased down the tube by releasing air, which allows additional cartridges to be inserted. The procedure is repeated until 40 or 50 cartridges have been inserted in the plastic tube. Air pressure is then applied to force them into the drilled hole. On the Lindö project, the air pressure used was 44 p.s.i.

Wagon-mounted Atlas Copco drills were used with a 52-ft. feed. These machines could drill down to 65 ft. Frames of I-beams and tracks of steel sheet piling permit longitudinal and transverse movement over the drilling area.

AB Skånska Cementgjuteriet, the well-known Swedish building and general construction firm, was the contractor for the project and evolved this system, using Atlas Copco compressors and drills and specially designed bits and crowns from the Sandvik works. The charging and blasting details have been worked out by another Swedish firm.

The reason for developing and using the "Lindö" method was mainly to avoid the danger of the surrounding slopes of wet clay and earth from caving in. This might have happened if conventional excavation methods had been resorted to. With the new method, a firm mixture of rock debris and surface layers was obtained, which was subsequently removed by means of a shovel dredge.

At the bottom of the planned canal the rock profile was very uneven, some peaks protruding almost to the surface and other parts lying much farther down. This condition presented various problems, both in the work of drilling and in calculating the necessary amount of explosive for each different hole. The largest blast was made up of 4,750 different charges and was highly successful in removing the biggest rock section at the fiord end of the canal. A total of 112,000 lb. of dynamite and 12,500 blasting caps were used in this large blast, being detonated in a series of 31 blasts at varying intervals. The current applied to start the delay elements' burning was carried through 300 miles of connecting wire. The blast broke up 36,000 cu. yd. of rock and lifted approximately 90,000 cu. yd. of overlying soil.

### Economic Expansion

After the Lindö Canal project has been completed, the growing port of Norrköping, located in a highly industrialized district of Sweden and having an extensive agricultural hinterland, will be more easily accessible to shipping than hitherto. The 4-mile-long and 33-ft.-deep Lindö Canal will replace a winding water lane that is now difficult to navigate because of its many shoals and islands. The greater depth will also benefit the busy Norrköping shipyard, enabling it to build larger vessels than has previously been possible.

The idea of a canal had been cherished since the 18th century, but the excavation difficulties had always been considered insurmountable.

**WAGON-MOUNTED: This close-up of the "Lindö" drill shows the drill pipe boring through soil. The projecting part immediately above the pipe is a special mechanism for rotating the pipe and the drill steel inside.**

# NEWS NOTES

### SHORT COURSE ON COMPUTERS

A short course on computers and computer applications for managerial and technical personnel in the mineral industries will be held at the University of Arizona from April 4 to 7, 1961. The purpose of the course is to familiarize people in responsible positions in the industry with the relatively new and rapidly expanding field of high-speed data processing. The course treats, specifically, computers and peripheral equipment, introduction to computer programming, mathematical techniques, and feasibility of computer utilization. Special emphasis will be given to applications of computers to the mineral industries.

Additional details, prices, and application forms may be secured from Professor E. R. Drevdahl, College of Mines, the University of Arizona, Tucson, Arizona.

### ROCK MECHANICS SYMPOSIUM

Both theory and practice will be covered by papers to be presented at the Fourth Symposium on Rock Mechanics, to be held at Penn State from March 30 to April 1, 1961.

The program consists of four technical sessions on: (1) behavior of rock under static loading; (2) behavior of rock under dynamic loading; (3) measurement of rock properties and stress instrumentation; and (4) ground control and subsidence.

The symposium is under the joint sponsorship of the departments of mining at Colorado School of Mines, University of Minnesota, Missouri School of Mines and Metallurgy, and the Pennsylvania State University.

### CABLE PROCESSING PRESS

A lightweight, portable, self-contained hydraulic press designed for processing cable on the job site is being manufactured and distributed by Mark Naught, Inc., of Portland, Oregon. Motivated solely by a hand lever, the "Mighty Mark" develops up to 15 tons of pressure and is used for cutting cable and making slings, eyes, chockers, and splices right on the job without necessitating the dismantling and transporting of cable to a shop for processing. According to the manufacturer, the compact new machine is easy to operate. Write to Mark Naught, Inc., for complete details.

### BUREAU OF MINES REPORTS

The U. S. Bureau of Mines has just issued two reports of interest to safety-minded operators.

Information Circular 8001, titled "American Standard Practice for Rock-Dusting Underground Bituminous-Coal and Lignite Mines to Prevent Coal-Dust Explosions," is the result of a study that revealed the former methods, adopted originally in 1925, had become, to a great extent, obsolete.

Standard explosion testing is the subject of the bulletin entitled "Laboratory Equipment and Test Procedures for Evaluating Explosibility of Dusts."

Copies of these bulletins may be obtained from the U. S. Bureau of Mines, Publications-Distribution Section, 4800 Forbes Avenue, Pittsburgh 13, Pennsylvania.

### COMPACT AIR COMPRESSOR

Introduction of a new 400-hp. stationary air compressor delivering 2,280 cu. ft. of air per minute was reported today by Atlas Copco, manufacturer of air compressors and pneumatic equipment.

The manufacturer claims this machine is designed for heavy-duty, three-shift operation in engineering factories, chemical plants, and other industrial locations as well as on construction jobs and in mines. Installation time is minimized since the compressor is delivered as a complete unit and only requires bolting to a simple steel frame preset in the concrete foundation. Designated the ER 8, the new Atlas Copco compressor is a two-stage, double-acting, water-cooled unit with cylinders placed in "L" arrangement. The manufacturer further claims accurate balancing and design reduce specific power consumption far below that of the majority of equal size machines. Further details may be obtained from Atlas Copco, 545 Fifth Avenue, New York 17, New York.

### FLAME-CUTTING MACHINES

A complete line of Oxweld flame-cutting machines is described in a 28-page catalog available from Linde Company, Division of Union Carbide Corporation. Machines described by the manufacturer range in size from small, handy portable machines that can be carried around a shop by one man to huge multi-torch shape-cutting machines capable of reproducing tens or thousands of the most intricate shapes and patterns in steel.

Also included are complete specifications for each machine, illustrations of typical installations, and a description of a wide variety of machine accessories.

Copies of the new catalog may be obtained by writing to Linde Company, Division of Union Carbide Corporation, 27 Park Avenue, New York 17, New York. Ask for Form 1396.

### EIMCO CATALOG

A listing of most major products of The Eimco Corporation of Salt Lake City, Utah, is included, with pictures, in a recently issued 18-page catalog-type booklet.

Included are pictures and short descriptions of the Eimco lines of tractors, loaders, mining equipment, process and filter equipment, and some of the products of the Eimco Foundry division. Also included are aerial views of the corporation's manufacturing facilities in Salt Lake City and a picture and short outline of activities of Eimco's Research and Development Center in Palatine, Illinois.

Copies of this catalog, "Quality Products from Eimco," will be sent upon request. Write for AP-20, The Eimco Corporation, P. O. Box 300, Salt Lake City 10, Utah.

### AIR LINE OILERS

A new and comprehensive bulletin on air line oilers, giving operational and specification data on oilers with half-pint to 5-gallon capacities, is available from Gardner-Denver Company.

Bulletin LO-2 describes the company's various size oiler models and lists the data on care and operation of pipe lines, hoses, and lubrication. Graphically illustrated, the brochure points out the advantages of line oilers.

Copies may be obtained by contacting the Gardner-Denver Company, Quincy, Illinois. Ask for Bulletin LO-2.

### SAFETY BROCHURE

A completely new selection of eye- and face-protection devices for a wide variety of industrial applications is described in a brochure available from Mine Safety Appliances Company, Pittsburgh.

Highlighted in the 40-page catalog is the Sightgard line of eyewear, which, according to the manufacturer, combines maximum protection with the distinctive appearance of modern functional spectacles. The manufacturer claims this eye protection provides high optical quality and impact strength in excess of specifications, and meets individual needs and preferences through a variety of frames, temple styles, bridges, and lenses. Also reviewed in the catalog are vision-testing equipment, goggles, faceshields, welding helmets, accessories, and parts.

Copies of the brochure, No. 0300-1, may be obtained by writing to Mine Safety Appliances Company, 201 North Braddock Avenue, Pittsburgh 8, Pennsylvania.


REFLECTING OUR BROADENING ENGINEERING SERVICES

THE VIBRATION ENGINEERING CO., INC.

Announces that Effective January 1, 1961

The Company Name has been Changed to —

VIBRA-TECH ENGINEERS, INC.

*In all other respects — services, personnel, office addresses, etc. — the corporate structure remains unchanged*

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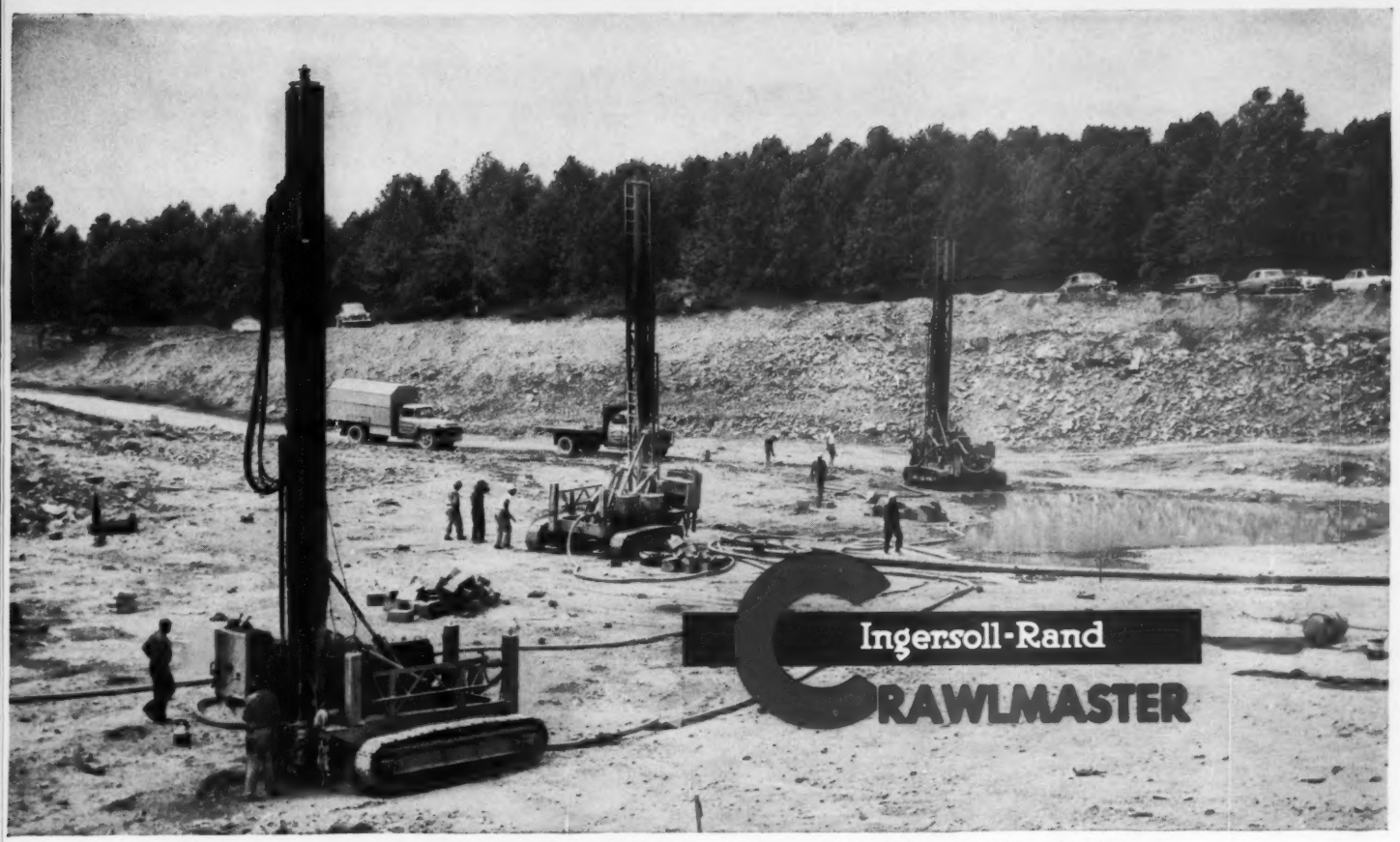
PHONE: GL 5-1961

PITTSBURGH AREA OFFICE
BOX 431, BRADFORDWOODS, PA.
PHONE: WEXFORD, PA.—WE 5-1655




E. J. Petrillo's Yonkers Contracting Co. speeds drilling of 3½ million yard cut at Jugtown Mountain with three Ingersoll-Rand Crawlmasters.

# new **SUPER-POWER** crawler drills help move Jugtown Mountain

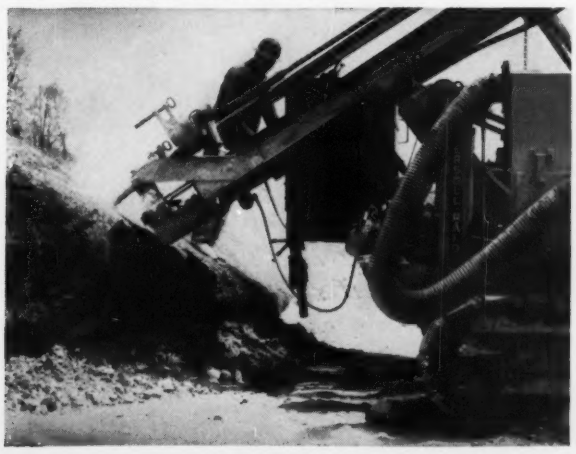
In one of the largest highway road cuts east of the Mississippi, a 3½ million cubic yard "bite" is being taken out of Jugtown Mountain near Phillipsburg, N. J. The 117-ft deep cut requires removal of a million and a half cubic yards of granite gneiss—and the heavy drilling is being done by three of Ingersoll-Rand's new hydraulic-feed Crawlmaster drills.

Purchased for this job after competitive tests, the Crawlmasters are putting down 4½" holes 18 to 20 ft deep spaced on a 9 x 10 ft grid. Using the new D-525 drifter with 5¼" bore, they easily out-drilled two 5½" bore machines and are heavier and more ruggedly built throughout. Outstanding features include constant-pressure hydraulic feed and retraction, throttle-controlled reverse rotation, hydraulic tower positioning from vertical to horizontal, rugged tractor-type crawlers with enclosed gear drive from two 11½-hp air motors, and four 30" stroke hydraulic leveling jacks. Capable of percussion, rotary or Downhole drilling of 4" to 6½" holes at any angle, the Crawlmaster is the most rugged and versatile machine of its type ever developed.

Supplementary drilling on steep slopes is done by six Crawl-IR drills and all air for the project is provided by one 900-cfm and six 600-cfm Gyro-Flo portable compressors.

Ask your Ingersoll-Rand engineer for the complete Crawlmaster story—or send for Bulletin 4211.

One of the Crawlmasters makes short work of angle-drilling a larger boulder.



**Ingersoll-Rand**
32A5 ♥ 11 Broadway, New York 4, N. Y.

*A CONSTANT STANDARD OF QUALITY IN EVERYTHING YOU NEED FOR DRILLING ROCK*

# JOY 60-BH CHAMPION

## OFF-THE-END DRILLING

For applications where large blast holes are sunk close to the rim of the highwall, Joy offers a new off-the-end version of the 60-BH. All models of the 60-BH Champion now have heavier crawler and mast assemblies, a larger capacity air compressor and can be specially rigged for optional use with a down the hole tool.

The 60-BH's are the largest models of the complete Joy Champion line. Your Joy engineer can give you an impartial appraisal of your drilling problems and recommend the proper Joy Champion from the most complete line of rotary air blast drills available . . . hole sizes from 5⅝" to 12". For complete information on the newest Joy Champion, the off-the-end 60-BH, write for Bulletin 2655-5.

**JOY**

**Joy Manufacturing Company**
**Oliver Building, Pittsburgh 22, Pa.**
In Canada: Joy Manufacturing Company (Canada) Limited, Galt, Ontario

# Hard blasting jobs simplified by using PRIMACORD® Detonating Fuse

In each of these examples the contractor *saved time* in loading and hooking up the blast. He *reduced the danger* of prematures and missed holes. And he got the *results* he wanted.

How? By using Primacord to prime each charge. *This saved time.* Because Primacord cannot be set off by normal vibration, sparks or stray electrical currents, but must be detonated with fuse and cap or electric blasting cap, *greater safety was assured.* And as for *results* — read these case histories.

## . . . on land

**Primacord saved time on two contracts for the relocation of Route 8 in Harwinton, Conn. Savin Bros., Bloomfield, Conn., sub-contracted the drilling and blasting to Rock Construction, Inc., Kingston, N.Y., who used 3" and 6" holes in some two million yards of tough rubbery mica schist. Cuts or lifts average 25 feet with 3" holes in 7' x 8' patterns and 6" holes on 12' x 12' patterns. Use of 40% Extra Dynamite in a ratio of approximately one pound per yard of rock gave the desired fragmentation. Holes were pre-loaded soon after drilling, and deck loaded whenever necessary for maximum fragmentation — all without fear of premature shots.**

## . . . in the air

**This condemned drawbridge at Summit Bridge, Del., could not support the equipment needed for torch cutting. So it was blasted down with 145 lbs. of high nitroglycerin-type explosive, primed and hooked up with Primacord. When all was ready for the blast, the Primacord trunkline, which connected explosives at several points, was detonated with an electric blasting cap. Professional Dynamiter: Jack Loizeaux, Baltimore, Md.**

Photo: Max Araujo

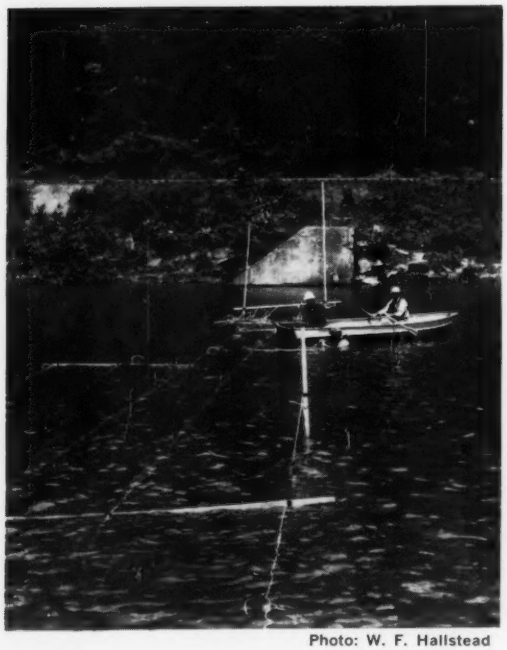
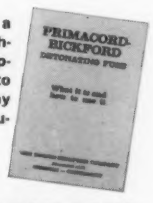


Photo: W. F. Hallstead

## . . . and under water, too

**The use of Primacord simplified the job of priming and hooking up approximately 750 holes under water in the Monongahela River, near Morgantown, W. Va. U. S. Corps Engrs. engaged Controlled Demolition, Inc., Baltimore, Md., to remove an old concrete dam 447 ft. long and a back wall 350 ft. long — representing over 75,000 cu. yds. of concrete. Multiple rows of vertical holes were drilled in the wet — primed and hooked up with Primacord.**

**Just off the presses! New edition Primacord book is a catalog and condensed manual of proved blasting techniques using standard Primacord types in mining, stripping, quarrying, ditching and construction work. Write to the Company for free copy; give name, title and company address. Also available through your explosives manufacturer.**

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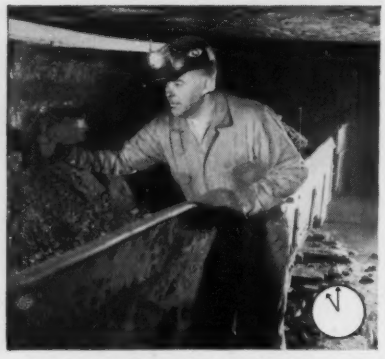
**THE ENSIGN-BICKFORD COMPANY**

*Simsbury, Connecticut • Since 1836*

## *A Typical Day with a Hercules Representative*

**AN EARLY START** enables Bob Shiel, Hercules technical serviceman, to observe step-by-step blasting procedures at his customer's mine.

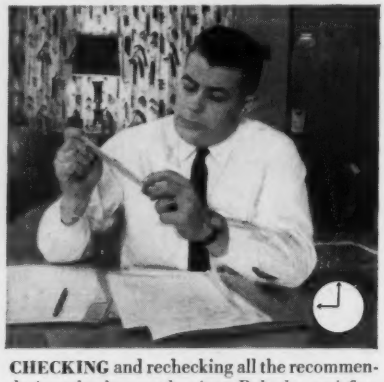
**CLOSE CONTACT** between Bob and the mine superintendent eliminates most blasting troubles, and increases the operating economy of the mine.



**UNDERGROUND** with the tools of the trade, Bob examines some of the cars of blasted material to determine the effectiveness of the explosive charges.

**BLASTING-PROCEDURE** observation is a part of Bob's work. It takes the guesswork out of his job, and enables him to specify the proper explosives.

**SHOP TALK** helps find out if the remedy he's suggested has cured this mine's troubles. Bob's background gives him the insight necessary to make intelligent recommendations.



**CHECKING** and rechecking all the recommendations he has made gives Bob the satisfaction of knowing that he has been of assistance in solving his customer's blasting troubles.

### Around the nation—around the clock

# THERE'S ALWAYS A HERCULES MAN READY TO HELP YOU

Bob Shiel, E.M., Ohio State, is just one of the many specially trained Hercules men serving the explosives-consuming industries. For years Hercules has employed men with engineering training to sell and service its explosives throughout the United States and in many foreign lands. Our experience has proved that men with engineering training can meet their customers on common ground. They speak the same language, for most of the men who direct explosives-consuming work are technically trained.

When a young engineer starts his training as an explosives sales engineer with Hercules, he begins a period of orientation. He is then sent to our explosives plants and laboratories for thorough groundwork in products and processes. Upon completion of this indoctrination, he visits various sections of the country where he learns how explosives are used in underground and open-pit mines, rock quarries, heavy-construction jobs, and seismic exploration.

The cornerstone of Hercules Explosives Department is based on men who have the know-how to handle blasting problems quickly, efficiently, economically. To take advantage of this specialized service, call or write.

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